BROACHES AND BROACHING

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BY

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PREFACE

Just how far back the knowledge of broaching dates is not known, though the great Leonardo Da Vinci, who was born in 1452 and died in 1519, made numerous sketches in his note books, depicting the broach in practically the forms used today, but it is extremely doubtful if he or his immediate successors made use of them; it shows, nevertheless, how far ahead the gigantic genius of the Florentine saw, to outline tools and machines that are just being appreciated.

However early the broach may have been invented, it is only in recent years that it has shown signs of taking the place its merits deserve. As one of the numerous branches of mechanics which owes its principal development to the evolution of the automobile, broaching has grown enormously in application, and is used today to a considerable extent in almost every branch of mechanical industry, and so quietly has it spread that few realize its great importance.

It is to bring to the attention of those who would know more of broaching work and machinery as it exists at present that this book has been compiled, thereby placing in their hands data that will enable them to judge whether it is applicable to their particular class of work or not, and if it is, to give them whatever working directions and advice I have been able to gather.

ETHAN VIALL.

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BROACHES AND BROACHING

CHAPTER I

BROACHING AND BROACHING TOOLS

Just what machine work may be classed as broaching and what may not, is, like so many other mechanical questions, not so easy to answer as it looks. It is common shop practice to class many shop jobs worked out with a single-point tool as broaching, whether the work is done on a shaper, punch press, keyseater, mandrel press or some other machine or device. However, no one ventures to call the work of a slotter broaching.

What then are the boundaries within which work may properly be classed as broached work? Everyone admits without argument, that holes finished to certain sizes or shapes by the use of tools having a number of teeth of increasing size is broaching, no matter whether the tools are pushed or pulled through.

Again, it is evident that a hole finished to size at one pass, by means of a single-point tool forced through by any means whatever, whether by the ram of a shaper, a punch press, a mandrel press or a hammer, is *not* broaching. It is either punching or drifting. Neither can the working out of a hole or recess, in a number of cuts, by means of a single-point tool held in a shaper, punch press or other machine, be called broaching. It is slotting.

A case that is not so clear, perhaps, is the work of a keyseater using a multiple-tooth cutter. Where the keyseat is finished at one pass with a tool having a number of teeth of increasing size, it is broaching. If it requires several passes to finish the keyseat with this kind of tool, it is still broaching, as the successive cuts simply take the place of the passage of several broaches of increasing size. However, if the tool has a number of teeth, and all are the same cutting length or size, and it is not backed by a taper strip to give the effect of increasing tooth sizes, it is a saw and not a broach. It might be well to state here, that the common file is also in the saw class.

Sometimes in cutting slots or certain shapes to a shoulder, it is impossible to use a single broach with a number of teeth, and it becomes necessary to employ several tools carried in a turret or otherwise, each successive cutter having the proper shape and the correct increase in size, to produce finally the finished hole. This also is broaching, as the different cutters represent the successive teeth of a single broach, which would be employed did not the shoulder prevent.

Almost innumerable examples might be cited, but these are sufficient, and taking the various factors into consideration, the following definition seems to cover the case: *Broaching is the working out of holes or slots, or the machining of surfaces, by tools having a number of successive cutting teeth of increasing size, no matter whether these teeth are arranged singly or in multiple.*

THE USES OF BROACHING TOOLS

Originally broaches were principally used to finish square holes, round holes and keyways. Then gradually they began to be used for splines, irregular-shaped holes, internal gears and numerous other applications of internal finishing. Later external broaching was used for a variety of work, though so far it is used very little in comparison to internal broaching.

No other machine-shop operation has relatively extended so rapidly in use during the last few years as broaching. Only a little while ago, it was looked upon as a very special method of machining. It was not considered in the same class as the then common operations. But this has been changed with surprising rapidity.

The tremendous improvements made on broaching machines and broaching tools, are largely the direct result of many years of experience and effort on the part of a small group of men who will be given their proper share of credit farther along in this book. The improvements made have greatly cheapened the cost of production in broaching various kinds of work. It is remarkable how interesting the proposition has grown since it has become so specialized. Broaching is now at a point where it is considered indispensable on certain classes of work.

One great advantage of broaching as a means of finishing certain parts, over machining by any other method, is that the action of the broach itself serves as a clamping medium and often nothing else is needed to hold the work in place, it being slipped on the work bushing or broach shank in a loose manner according to the work to be done. The work then becomes fastened in its proper position as soon as the machine is started. This single item is of great importance in many cases where the chucking of an irregular piece, in order to finish it by boring or reaming, would be extremely difficult. In a great many cases the operation of broaching may be finished in the time ordinarily taken to chuck the piece. In the case of an ordinary keyway, for instance, no clamps or setting devices are needed other than a guide bushing and in many instances this is dispensed with. As a rule the keyway is finished in one operation and but 1 min. of time is consumed. Sometimes three or four pieces can be done in one operation, thus increasing the usual output that many times.

For broaching square holes or other shapes, when the part is not over 2 in. long, the work can usually be done in one operation, or in from 1 to 2½ min. Longer pieces will usually require the passage of two or more broaches, the time being increased correspondingly.

Another great advantage of the broaching method is the fact that there is so little resulting scrap. One large automobile factory, which was probably the first to use broaching to any extent, kept account of 10,000 pieces

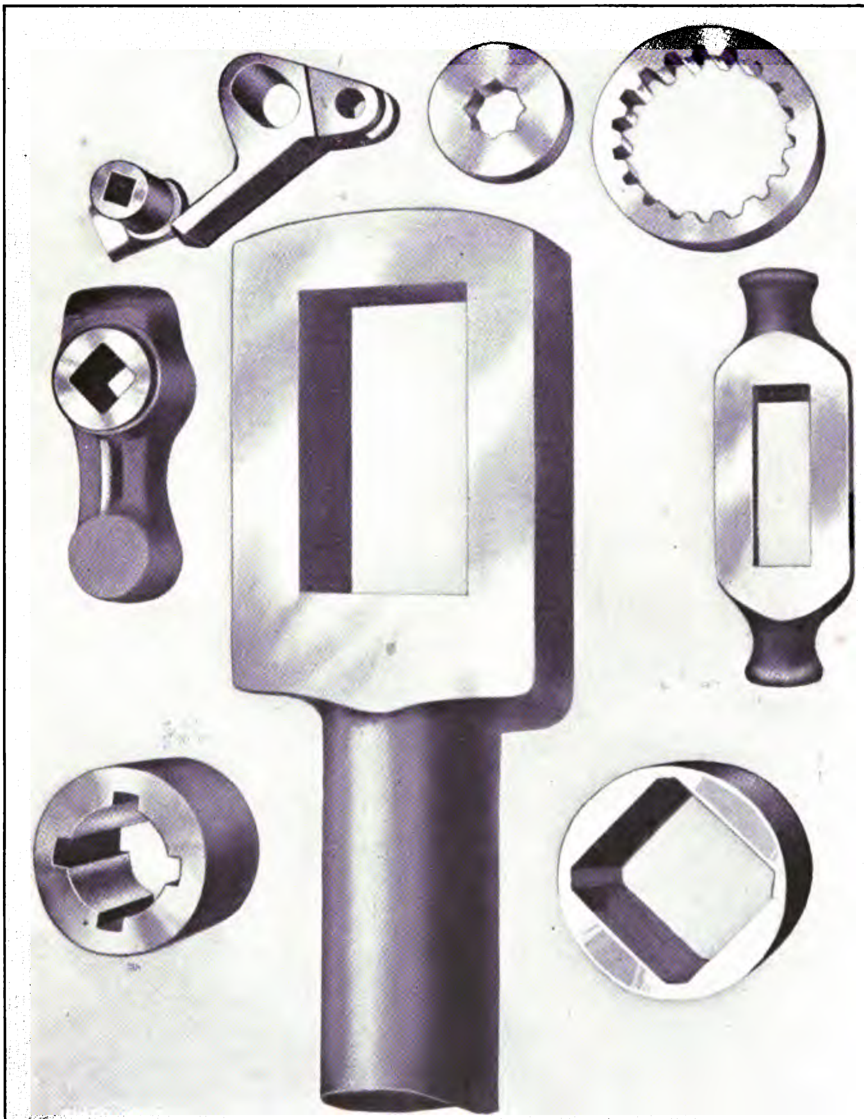


FIG. 1.—Examples of broached work.

of all kinds, and found that less than 1 per cent. were spoiled in the process, a record not approached by any other method of machining. Nor is the expense of making broaches and maintaining sizes at all excessive, when the

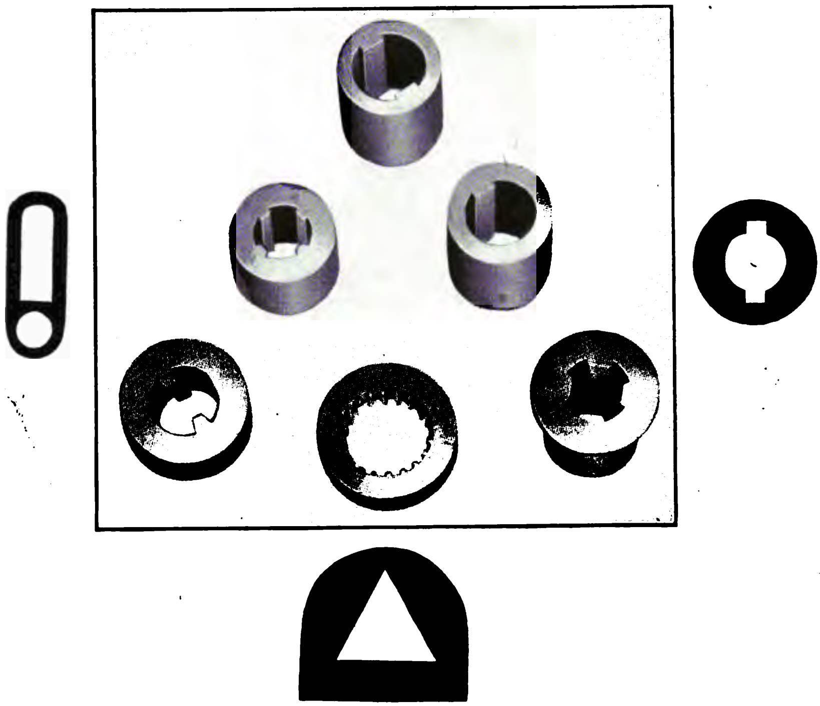


FIG. 2.—More examples of broaching.

tools are properly made, and judged by the accurate and quick results obtained on the work, they are extremely economical tools for the work to which they are suited.

A few of the more common examples of broaching work are shown in Figs. 1 and 2. These represent pieces being broached daily in scores of shops in all parts of the country. Some of these pieces will be taken up in detail later. Other pieces more difficult or especially interesting for various reasons will also be shown and described together with the machines and broaches used in each case.

TYPES OF BROACHES

In Figs. 3 and 4 are shown some of the varieties of broaches for internal work. A majority of those shown are of the pull type, though a few of the push type are shown in Fig. 4. In a general way the push broaches are shorter and heavier than the pull type, though they both have many characteristics in common. As a rule the push type of broach is used in a hydraulic press, though a crank, screw or hand press is often used. The pull type of broach is commonly used in a regular broaching machine, built especially for the purpose and unsuited to any other use. Shapers, planers, or other machines are sometimes fitted up for doing special broaching jobs where no regular machine is available. Various examples of all of these regular and special machines will be shown as we proceed. In the number of broaches illustrated are round, square, rectangular, spline, single keyway, double keyway, burnishing, three-step, inserted tooth and other types.

The teeth of a broach of either type may be solid or inserted according to size and uses. The teeth on round broaches may be either cut in spirals, something like a thread, or as usual with circular teeth having the edges parallel to each other. Rectangular broaches may have the teeth cut straight across or diagonally, the latter giving a beautifully shearing cut on certain kinds of steel or other metal. The spacing or pitch of the broach teeth may be even, or cut differentially in order to eliminate chatter, as in the common reamer. Broaches are also made for cutting helical grooves of various kinds. All these, and many more, will be taken up in their proper order and specific directions given for their design, manufacture, use and care. Before proceeding farther, however, the various types of standard broaching machines will be taken up, and the principal types and makes described in detail.

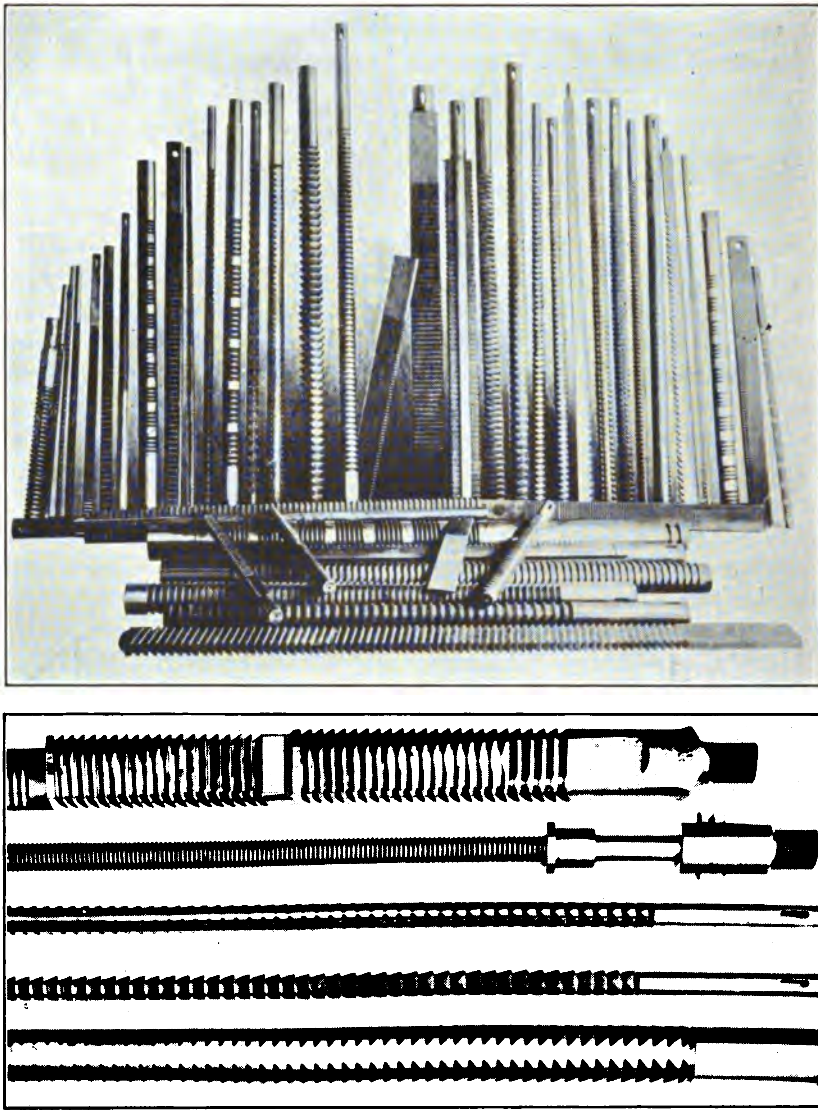


FIG. 3.—Typical examples of pull broaches.

FIG. 4—Examples of both push and pull broaches.

CHAPTER II

STANDARD TYPES OF BROACHING MACHINES

In classifying the machines described in this chapter as standard machines, we mean those that are manufactured expressly for broaching work and as such put on the open market. Strictly speaking, the machines of the pull, or draw type, are the only ones that can be classed alone as broaching machines since they are unsuitable for other work. However, several machines generally used for push broaching are included even though they may be used for a large variety of other work besides broaching. Allusion is here made to vertical hydraulic presses, or presses of that class, which are commonly used for push broaching work, yet are adapted to other work with no alterations in the machines themselves. No attempt will be made to make the list of machines of all types complete, as that will be left to the catalogs of the various makers, but enough will be shown to cover the better-known and more commonly used machines as they are found today. A few machines not included in this chapter may be found in the following chapters illustrating actual shop operations.

THE PULL TYPE OF MACHINE

The pull type of machine is divided into two general classes: First, those in which the drawhead is operated by means of a screw; and second, those in which the drawhead is operated by means of a rack and pinion. Those of the first class are far more numerous and will be shown and described before the others.

The machine shown in Fig. 5 may be taken as a representative specimen of the belt-drive, screw-operated broaching machine. It is made by the J. N. Lapointe Co., New London, Conn. This company builds broaching machines of various sizes, single and double screw and motor and belt drive. The smallest machine they make weighs approximately 445 lb. and has a capacity to cut a keyway 1/4 in. wide and of a reasonable length, and it will broach a hole 1/2 in. square and 1 in. long. The stroke of this small machine is 21 in. The machine shown in Fig. 5 weighs approximately 3750 lb. The driving pulley is 4 1/2 by 22 in.; size of driving screw, 3 3/4 in. in diameter; 1-in. pitch; stroke, 64 in.; travel of draw head when on low gear, 3 ft. per min.; travel of head when on high gear, 5 ft. per min.; capacity to cut from the smallest to the largest work practical to broach.

This machine has two positive geared speeds, suitable for light and heavy work; driving nut can be removed for replacement in 20 min., has large ball-bearing thrust taking all pressure and avoiding heating under heavy broach-

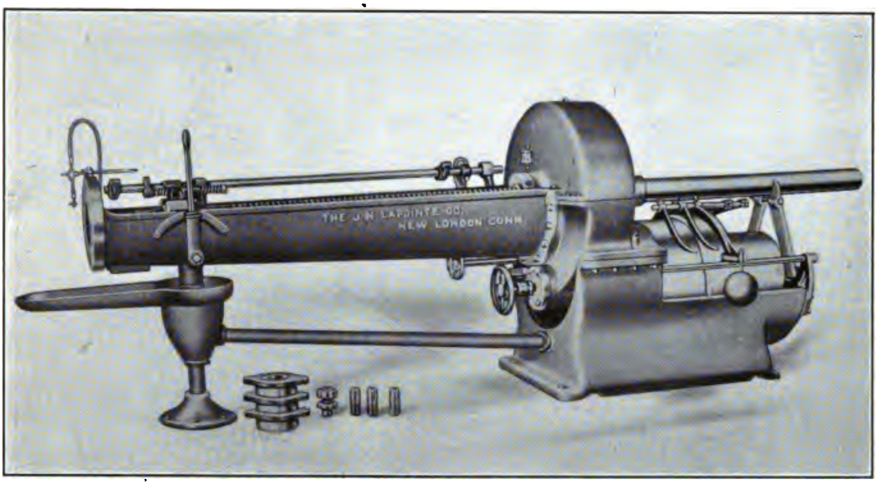


FIG. 5.—Typical screw-operated pull broaching machine.

ing cuts. The gears are self-lubricating, running in oil cases; driving screw is protected from dust and injury by a telescoping tube in rear of machine.

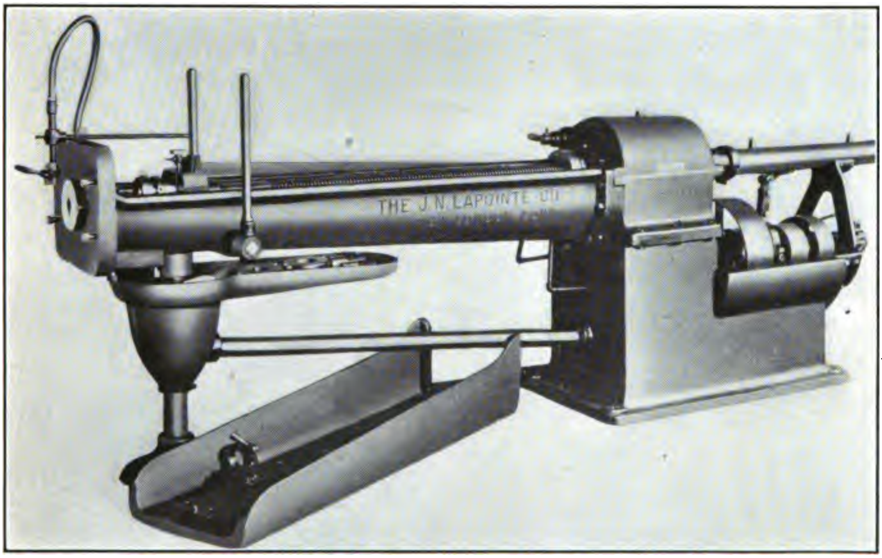


FIG. 6.—Pull type of machine fitted for outboard broach support.

Provision is made for attaching special fixtures on the front end not necessitating extra length broaches.

The machine shown in Fig. 6 is also made by the same company and along practically the same lines as the one just described except it is made to be fitted with a chip pan, such as shown under it. This chip pan carries a

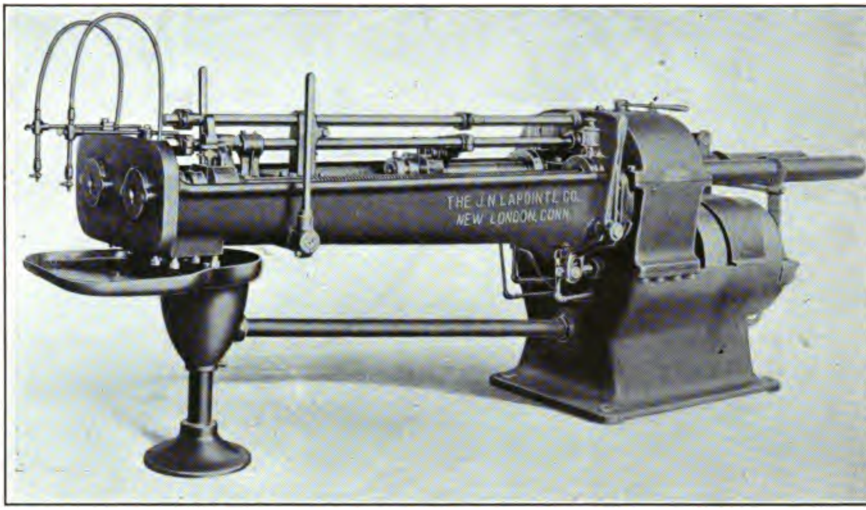


FIG. 7.—Broaching machine with two draw-heads and two screws.

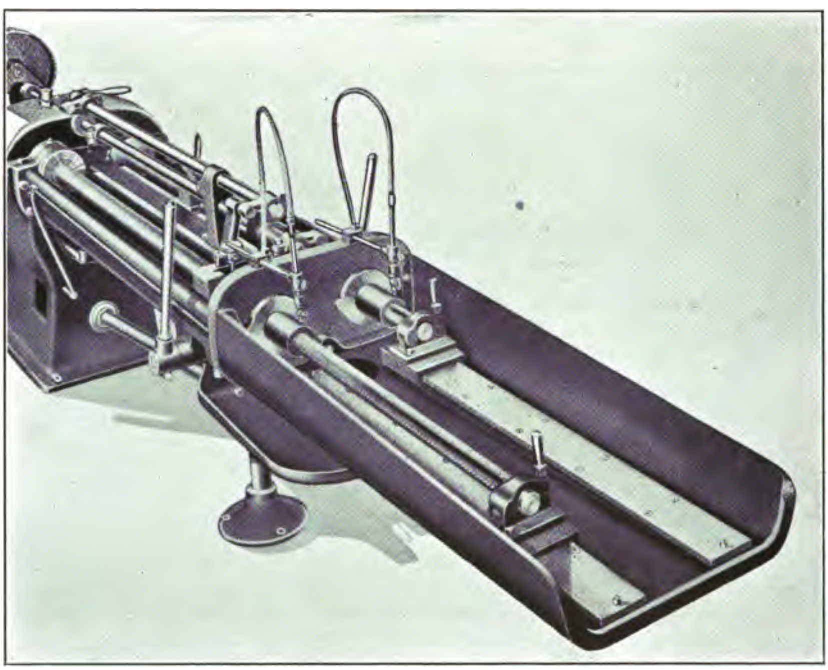


FIG. 8.—Double head machine with outboard broach supports.

sliding broach support, which is a very valuable feature on some classes of work where the end of the broach needs support. Otherwise the weight of

FIG. 9.—Broaching machine with motor drive.

a long broach would have a tendency to cut downward and make an untrue hole.

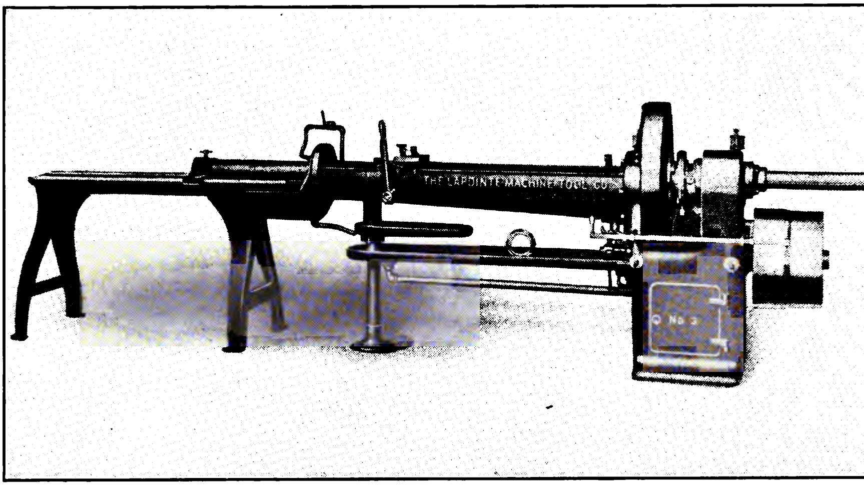


FIG. 10.—Machine with self-sustained broach support.

A somewhat similar machine, but built with double screws and draw-heads, is shown in Fig. 7. This machine is intended for shops having a large quantity of duplicate work to do. When this machine is in operation,

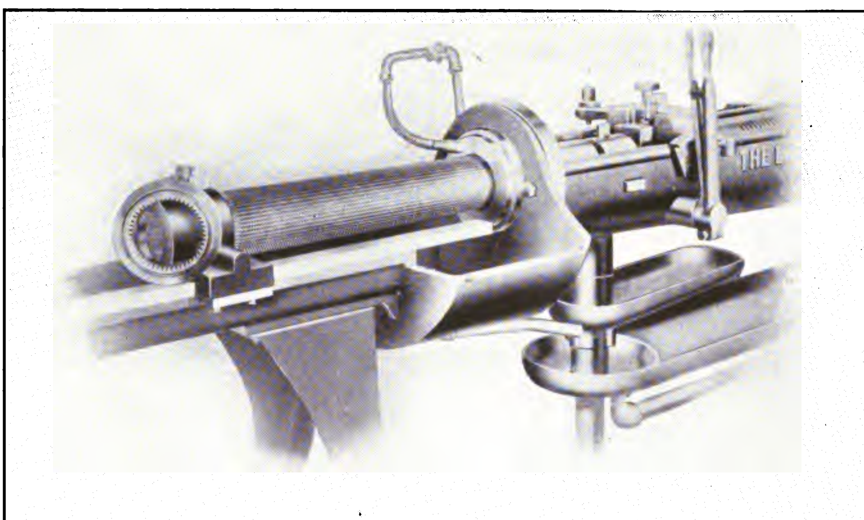


FIG. 11.—Close up view of heavy broach supported on guides.

one head is on the cutting stroke and the other on the return. The returning broach can be disconnected, cleaned up and prepared to operate on another piece by the time the other head has neared the end of its travel. The machine is so arranged that one screw may be disengaged, making it a single-screw machine when desired. The large size of this machine weighs 4800 lb., has a low and high speed of head travel of 3 ft. and 6 ft. per min. respectively. The screws are 2¾-in. in diameter, 2-in. pitch, 54-in. stroke. Capacity of machine up to 3-in. square holes. Floor space, 3 by 16 ft.

Fig. 8 shows one of these double-head machines fitted with a pan carrying slides and broach guide supports similar to the one shown with the single-head machine. All of these machines are also supplied with pumps and hose for flooding the work.

A machine built on lines of approved broaching practice by the Lapointe Machine Tool Co., Hudson, Mass., is shown in Fig. 9. It is motor-driven though this company furnishes either belt or motor drive. This particular machine weighs 2300 lb., has a capacity to cut keyways up to 1½ in. wide or broach square holes up to 3 in. across flats from a drilled hole in steel. The stroke is 50 in.; driving screw is 2¾ in. in diameter, 1½ threads per in.; cutting speed, 48 in. per min.; return speed, 225 in. per min.; floor space, to allow for screw travel and broach, 15 in. by 31 ft.; motor required, 5 hp. Oil pump and other necessary equipment is furnished.

A machine of the same class, except belt drive, built by the same firm, is shown in Fig. 10. This machine has a sliding broach support attached. This support is on the same principle as the one previously described, except that it is self-supporting and does not depend from the draw-head bracket.

A close-up view of this machine, showing a heavy internal gear broach in place, is shown in Fig. 11. This at once explains to the practical man the advantage of such a support for heavy tools. These supports are furnished to be fitted to the various sizes of machines made by this concern.

While the general looks of these machines do not differ materially, the sizes differ considerably, one of the larger models weighing 4900 lb. and having a screw 3½ in. in diameter and a 60-in. stroke, with a capacity for keyways 4 in. wide, or for holes 4 in. across the flats from a drilled hole in steel. The motor for this size machine is a 10-hp. and the floor space 54 by 226 in.

MACHINES OF THE RACK-AND-PINION CLASS

A machine typical of those using a rack in place of a screw to operate the draw head, and known as the Knowles type, is shown in Fig. 12. This machine is made by the Pawtucket Mfg. Co., Pawtucket, R. I. Two sizes of this machine are made, weighing respectively 1325 and 2450 lb. The smaller machine will broach keyways up to ⅝ by 5/16 in., 6 in. long; its cutter is 28½ in. long and the bar 49½ in.; extreme length of bed, 63 in.; width of rack, 2⅞ in.; length of stroke, 42 in.; standard speed of cutter bar, 7 ft. 4 in. per min.; floor space, allowing for bar and all, 11 ft. 5 in. by 3 ft. 2 in. The larger machine will broach keyways 1 by ½ in. by 12 in. long; extreme length of bed, 98 in.; width of rack, 6 in.; hole in head, 1 15/16 in.;

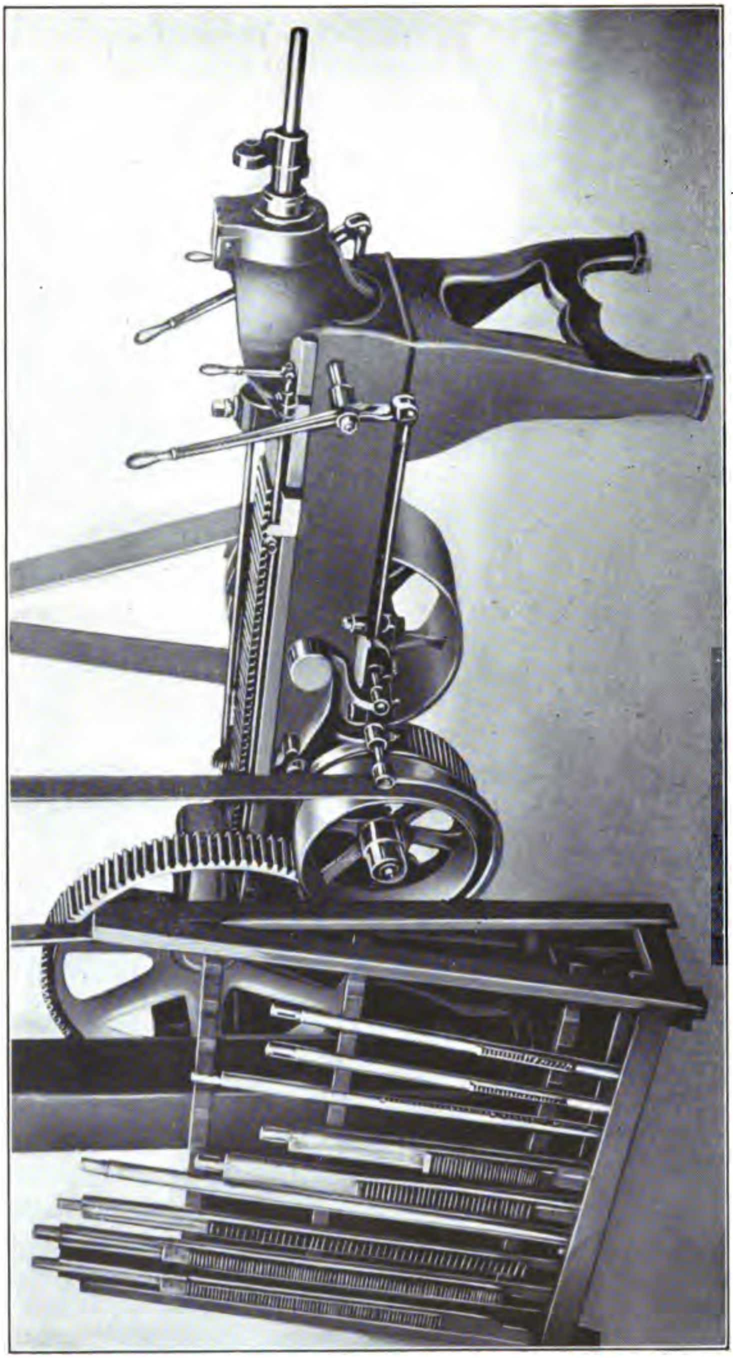


FIG 12.—The Knowles type of rack-and-pinion machine.

stroke, 59 in.; speed of cutter bar, 4 ft. 6 in. per min.; floor space, 16 ft. 6 in, by 3 ft. 10 in. When using these machines on steel an oiling attachment is used. These machines may be used for practically the same line of work as the screw-operated type, up to the limit of their capacity. As a rule, however, these machines are generally used for keyseating and work of that character rather than for the more complicated class of broaching. The machine shown is used in the shop of the New York Air Brake Co. for broaching valve seats and some of the special broaches used are shown on the rack at the left.

The broaching machine shown in Fig. 13, made by John T. Burr & Son Brooklyn, N. Y., is primarily a keyway cutter. The model shown is known

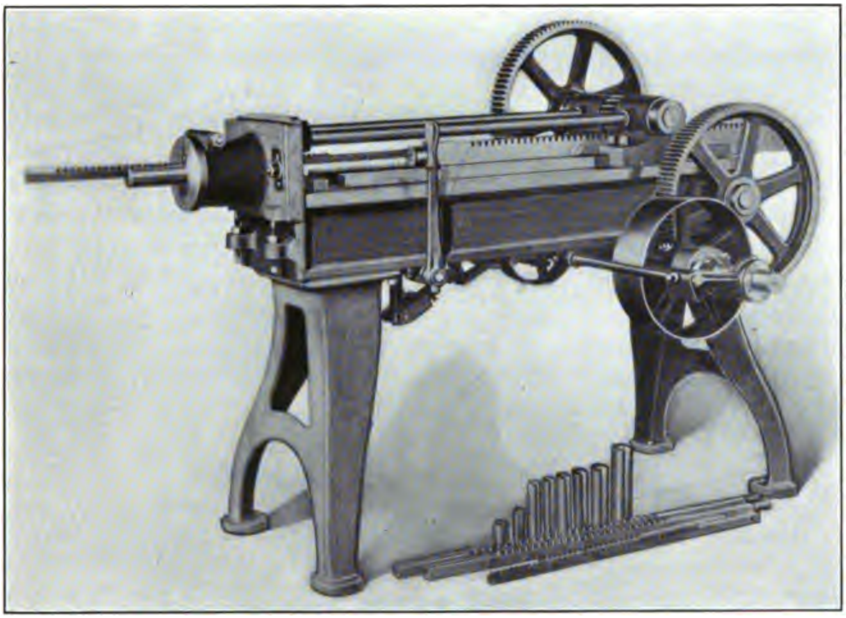


FIG. 13.—The Burr keyway broaching machine.

as their No. 4 Keyway Broaching Machine, and is of the rack-and-pinion type. The main boxes and face plate are tied together by a pair of distance rods, providing ample strength to resist the strains of broaching. The driving pulley is 20 in. in diameter for a 4-in. belt. The machine may be started, stopped or reversed at any point of its travel. Either straight or taper keyways are cut with equal facility by a single pass of the cutter, in from 10 to 20 sec. The largest keyway that can be cut is 5/8 by 5/16 by 6 in., and the weight is about 2000 lb.

The broaches used are of rectangular section, which reduces the bushings to the most inexpensive form. These bushings are simply round stock the size of the bore to be keyseated, channeled out to allow the broach to be drawn freely through. The channel is made deep enough for the insertion of either a straight or a taper bearing strip, so that both straight and taper keyways may be cut by using the same bushing with different bearing strips.

The foregoing four makes of machines cover the present-day field in the pull-broaching line as far as the public market is concerned. Other makes will be described later, but they are not machines that are on the open market.

Wherever the length of stroke is mentioned on any of these machines of either type, the maximum is meant, as all are adjustable to suit the work in hand.

MACHINES FOR PUSH BROACHING

Several classes of machines are used for push-broaching work. All of the standard ones are of the vertical type, as those for pull broaching are of the horizontal type, though exceptions may be found to both in special-built machines. In the vertical push-broaching machines are found hydraulic, screw, rack, crank and hand-operated lever machines. The hydraulic machines are far more commonly used than any other for push-broaching work, but most drawing presses are capable of being used for push-broaching work under favorable circumstances. Sometimes the ordinary punch press is used for broaching work of a limited nature. The well-known hand-operated mandrel presses are also frequently used for small amounts of light broaching work. No attempt will be made to cover the entire field of push-broaching machines, but a few of the better-known machines will be illustrated and described to give the reader an idea of the classes, range and capacities.

HYDRAULIC-OPERATED MACHINES

The press shown in Fig. 14 is but one of a number of models made by the Watson-Stillman Co., New York City. The particular machine shown has a capacity of 10 tons, and weighs about 1650 lb. It was designed for broaching small holes in automobile parts and for miscellaneous work in machine shops. The pump, which is mounted on top of the press, has three pistons 1¾ in. in diameter and of 1¼-in. stroke. The ram is double-acting and is 6 in. in diameter with piston areas proportioned to cause it to move down at the rate of 35 in. per min. and up 100 in. per min. when the shaft makes 100 r.p.m. Its motion, which is 12 in., is controlled by a special valve actuated by a lever. When the lever is in its central position the valve causes the water to circulate without disturbing the position of the ram. On moving the valve to one end the ram is forced downward, when moved to the other end the ram is raised.

The platen is 12 by 18 in. inside of the rods; the maximum vertical opening is 18 in.; the height from floor to face of lower platen is about 31 in.; the pulleys are 24 by 4 in., and the press as shown is 8 ft. 8 in. high.

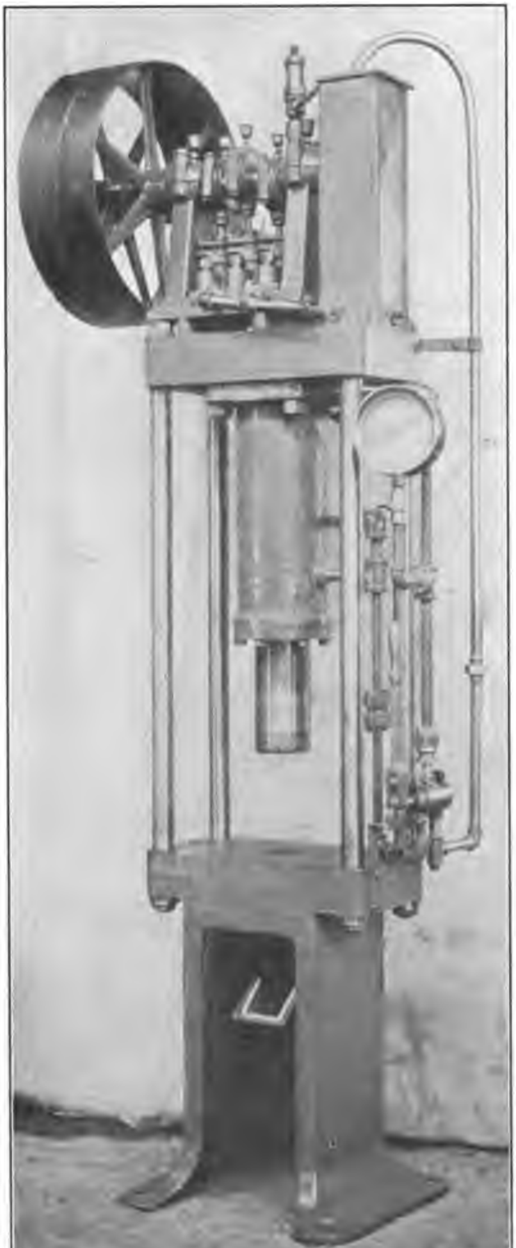


FIG. 14.—Watson-Stillman hydraulic broaching press.

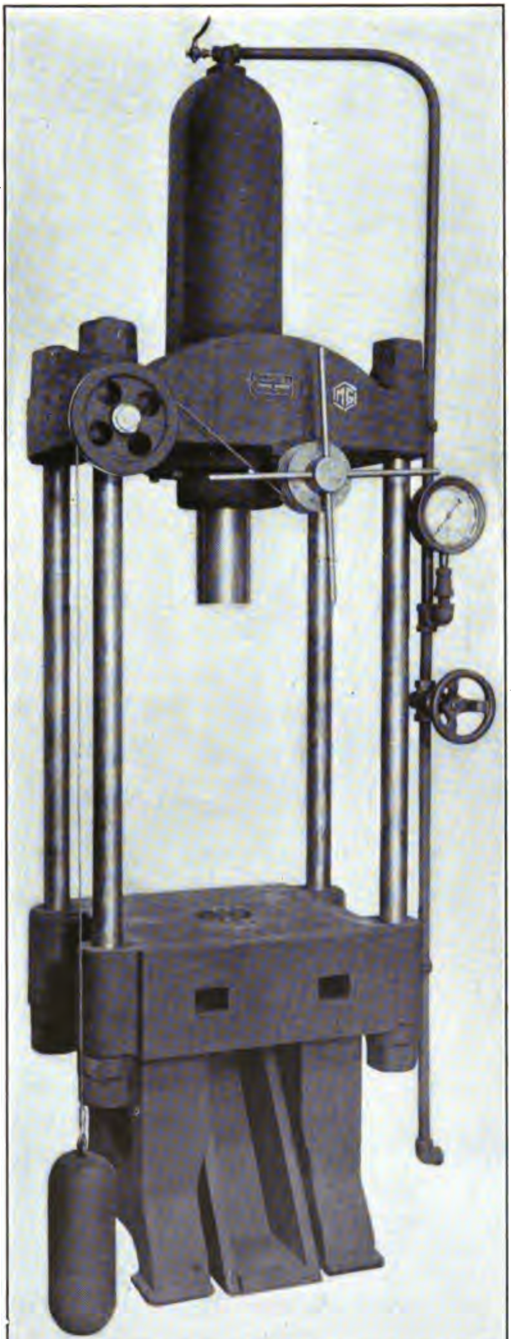


FIG. 15.—Press made by Hydraulic Press Mfg. Co.

This press is modified to suit requirements, and the company also makes other models, suitable for broaching work, up to 150 tons capacity, or more.

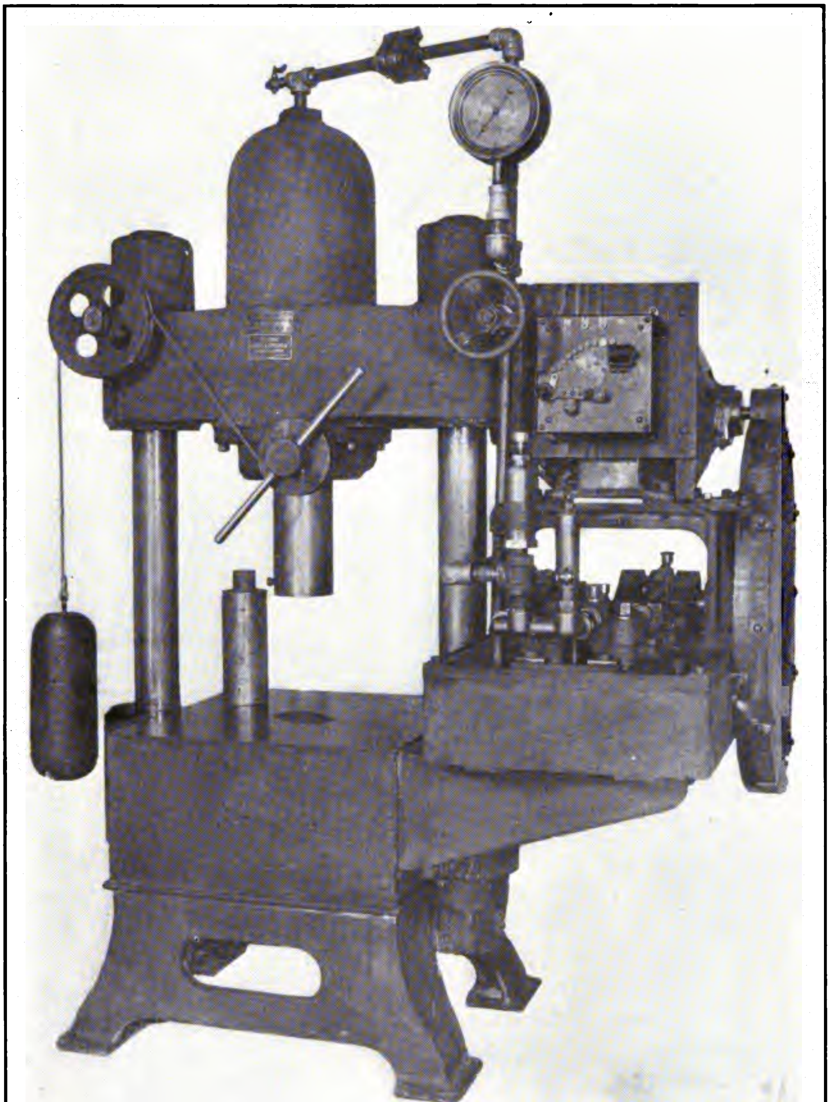


FIG. 16.—75-ton, self-contained broaching press.

The press shown in Fig. 15 is very similar to the one just described. It is made by the Hydraulic Press Mfg. Co., Mt. Gilead, Ohio. This company builds various models of broaching presses. In this machine, which is known as their No. 8 press, the ram is counterbalanced so that it can be run down to the work quickly and returned by the hand windlass attachment. The wood-lined box below catches the broach without injury as it drops after completing the operation. The specifications are: Diameter of ram, 8 in.; pressure capacity, 63 tons; size of platen, 24 by 24 in.; daylight space, 36 in.; run of ram, 24 in. It is operated from an accumulator or by a pump separate from the press, or by one mounted on it. A two-rod press of this type, but of 15 tons capacity, known as a No. 4, is also made. The various dimensions of this latter machine are approximately half those of the former.

Another machine built by the same firm is shown in Fig. 16. This is a self-contained machine with both motor and pump mounted on an extended base which is attached to one side of the press. It is suitable for the wide range of broaching and forcing work coming up in machine and automobile shops. The ram is counterbalanced and is controlled by a hand windlass operating with slight effort on the part of the operator. The ram can thus be raised or lowered to admit various sizes of work. When the ram is moved downward by the hand windlass the cylinder is filled with water by the vacuum which is caused by the ram's downward movement. By this action the pressure upon the broach or the material in the press is initiated as soon as the motor and pump are started.

The ram is fitted for extension blocks which may vary in shape or length according to the size of the pressing surface, or the height of the daylight space.

The ram of this press is operated by a two-plunger horizontal pump, having plunger diameters which if desired may vary from 5/8 to 1 in. but all having a stroke of 3 1/2 in. The pump is equipped with an automatic knock-out attachment which limits the pressure to predetermined maximum point. This may be any pressure which the material requires within the maximum rated capacity of the press. All parts of the pump are easily accessible, thus eliminating difficulty in making adjustments and repacking the pump plungers. The pump shown in the accompanying illustration has a single reduction of gears. It may, however, be equipped with a double reduction should it be desired. The motor and starting rheostat are conveniently located, being within the easy reach of the press operator. A motor of 2-hp. capacity is required.

The speed at which this press may be operated varies with the plunger diameters of the pump. The larger the pump plungers the more rapid will be the movement of the ram, more water being forced into the cylinder at one stroke of the pump.

The press as shown in the illustration has a 10-in. ram upon which can be initiated a maximum pressure capacity of 75 tons. The entire press proper is of steel construction, the beams being formed by steel lugs cast on the cylinder while the sills are formed by steel lugs cast on the base plate. Bright cold-rolled steel shafting is used for the strain rods.

The two brackets which form the pump base are cast iron and are bolted

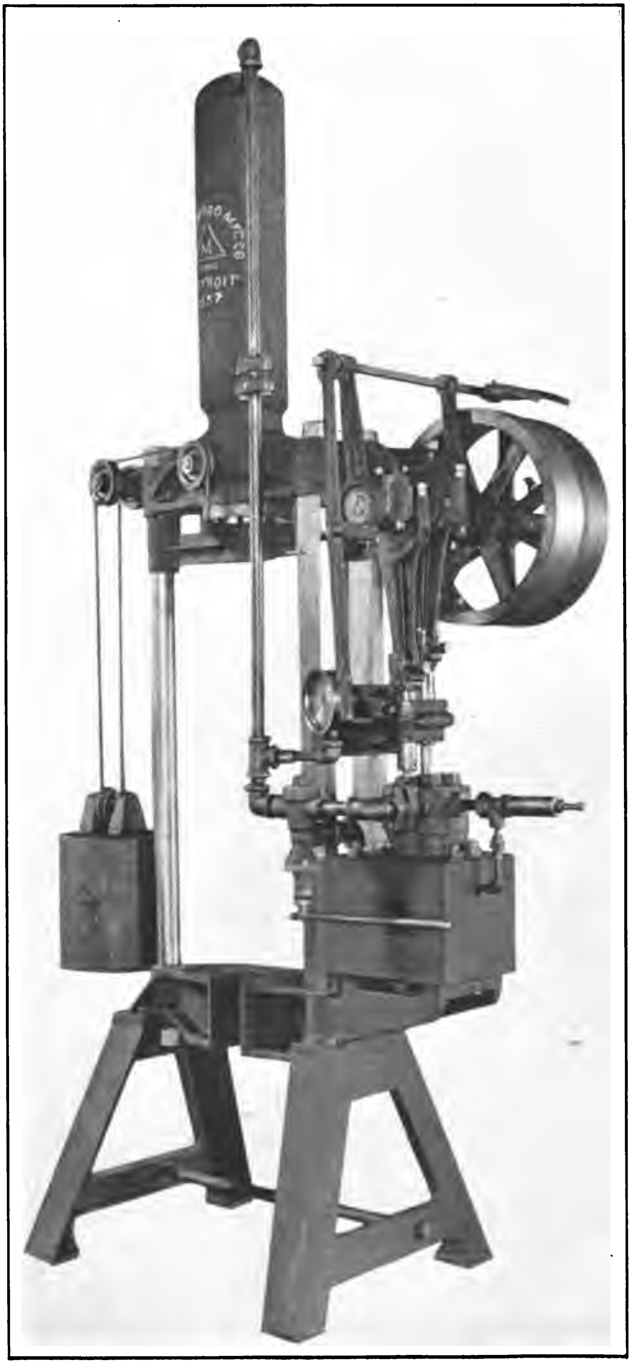


FIG. 17.—35-ton Metalwood press.

securely to the main part of the press. Bolts are used here because it is sometimes desirable to operate the press from an independent pump or an accumulator system. The motor base in this case is omitted.

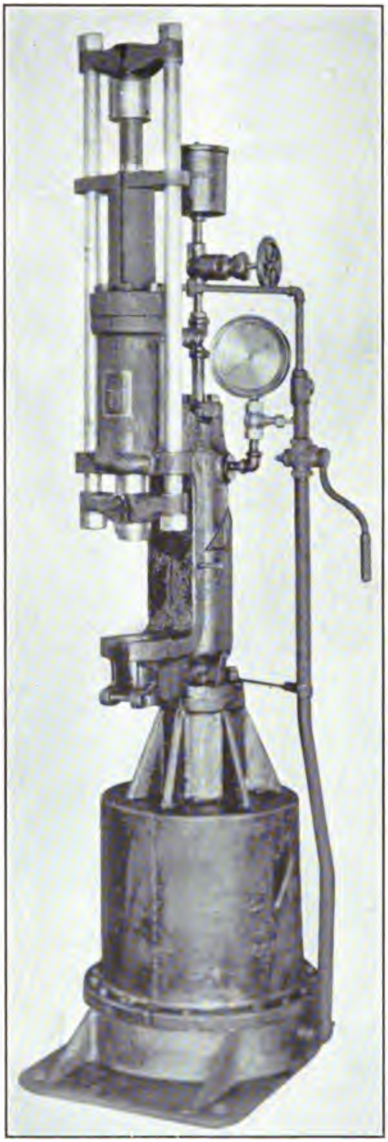


FIG. 18.—A 10-ton light broaching press.

The daylight or stock space of this press is 18 in. with a 12-in. run of ram. The press bed or pressing surface is 24 in. square. The press bed has an opening directly under the ram to receive the broach as it passes through the work. A wooden box receives it as it drops. The extreme height of the press is 6 ft. 4 in.

A press made by the Metalwood Mfg. Co., Detroit, Mich., is shown in Fig. 17. This machine has an adjustable safety valve for the pump to prevent overload, or it can be adjusted to a predetermined pressure. The pump is controlled by a Metalwood single-lever quick-operating valve, giving control of speed of ram, pressure applied and return of ram. Ram is returned automatically at any predetermined stroke. All hydraulic connections are of seamless steel tubing and drop-forged steel fittings. It is equipped with a gage reading in pounds per square inch and tons applied on ram or work. The principal specifications are: Ram, 4½ in. in diameter; stroke, maximum, 30 in.; cutting speed, 4½ ft. per min.; pull-back, weighted; distance between columns, 23¼ in.; distance between ram and platen, 44 in.; platen to floor, 31 in.; hole in platen, 4 in.; height overall, 10 ft. 6 in.; floor space, 32 by 39 in.; weight, 3200 lb.; pressure capacity, 35 tons.

A smaller-size press, also built by the Metalwood company, is shown in Fig. 18. This is a very convenient size for certain kinds of work. The machines are made in 10, 15 and 20 tons capacity. An air pull-back operating at 100 lb. pressure insures quick action, the operation being controlled by the lever shown at the right. The ram stroke on the three sizes respectively is 6, 6 and 18 in. and work 9, 9 and 15 in. in diameter is taken. The weights are 900, 1400 and 3200 lb.

A SCREW-OPERATED VERTICAL PRESS

The broaching press shown in Fig. 19 is a vertical screw-operated machine made by the Standard Machinery Co., Providence, R. I. It has a variable stroke mechanism which can be adjusted to operate through any intermediate distance between the extremes. The large screw operates the ram or slide, the speed of which can be varied by changing the gear ratio on top of the machine, or by giving the drive belt a different speed. The ram has a constant speed throughout the stroke. A quick return and an automatic stop are provided. Two sizes of this machine are built, the larger requiring about 10 hp. The capacities and specifications of these two sizes are 20 and 40 tons; stroke, 7 and 12 in.; diameter of screw, 2½ and 4½ in.; pitch (double) ½ and 1 in. (single); height overall, 6 ft. 2 in. and 7 ft. 9 in.; work space, 13 by 15 in. by 10 in. high and 16 by 19 in. by 10 in. high; weight 2000 and 5200 lb.

A HAND-OPERATED PRESS

The hand press, Fig. 20, made by the Atlas Press Co., Kalamazoo, Mich., may be taken as typical of presses of this class. It is suitable for numerous broaching jobs, which will be elaborated upon later. This press may be used mounted upon a base as shown, upon a bench or upon some other machine, such as the end of a lathe bed. The pinions on these presses are made of chrome-vanadium steel forgings. The rams are of high-carbon nickel steel. It will take work up to 20 in. in diameter; has a capacity over

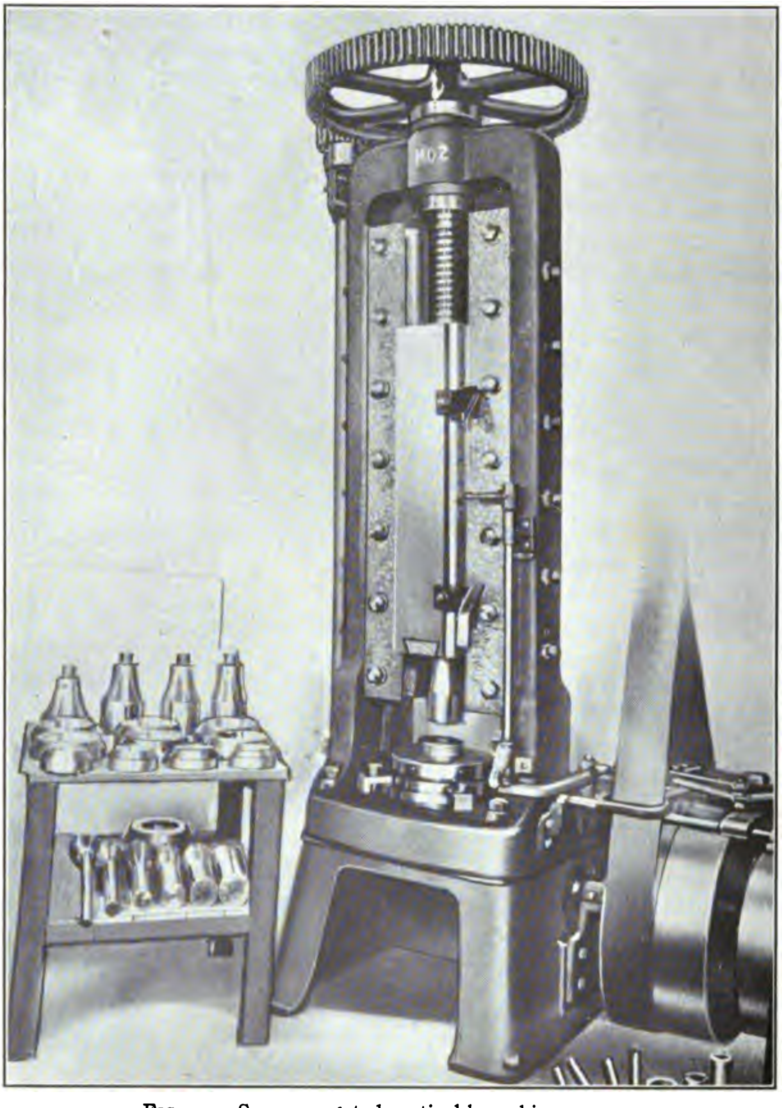


FIG. 19.—Screw-operated vertical broaching press.

table of 18 in.; ram is 2 by 2 in. by 24 in. long; floor space of pedestal, 22 by 29 in.; weight of pedestal, 375 lb.; weight of head, 550 lb.; leverage, 160 to 1; capacity, 10 tons pressure. This press is known as their No. 3, but a number of others suitable for broaching work are also made.

FIG. 20.—Atlas hand-operated broaching press.

CHAPTER III

EXAMPLES OF PULL-BROACHING WORK AND PRACTICE

The simplest and most common broaching work is that of cutting keyways. For this the pull broach is practically in a class by itself, though in some cases push broaches are used. For gears, cams, flywheels, sleeves, levers and the like, where keyways are to be cut in considerable numbers, no other method can compare with broaching in speed, accuracy or economy. Only on small quantities or unusual sizes of work are other methods preferable. The time taken to broach out a keyway, of course, varies with the size and length of the keyway and the metal being broached. As a general rule, any ordinary keyway may be broached at one pass with a single broach, though occasionally two or more broaches have to be used; especially is this true if the keyway is of unusual size and the metal tough. Where the work is comparatively thin, several pieces are often broached at once with one pass of the tool. The shape of a piece, however, does not always lend itself to this.

A good example of keyway broaching is done on Ford automobile wheel hubs. Keyways 1/4 by 1/8 in. and 3 1/4 in. long in a tapered hole are cut on a Lapointe machine at the rate of 100 per hr. Another case where keyways 5/16 in. wide by 5/32 in. deep, and 4 in. long were cut in steel, the time required was less than a minute, which included the cutting and the placing and removal of the piece.

For ordinary keyway cutting, only a work bushing, which also is a guide for the broach, is used to hold and locate the piece. The action of the broach as it is drawn in serves to hold the work securely in place on the bushing and against the face-plate of the machine. As soon as the broach has finished cutting the work is simply pulled off by the operator. The broach is then run out to starting position and another piece placed on the work bushing ready for the next cut.

The machine shown in Fig. 21 gives a good illustration of common keyway work. The piece shown in the machine is a long sleeved gear but the method of locating and holding the work is exactly the same as used for work not so long. Other examples of work are shown just in front of the machine and as all are bored the same size and all have the same-sized keyway broached in them, the same work bushing and broach does for all. The steel sleeve *A* 13 in. long, is having a 1/2-in. keyway 1/4 in. deep broached in it at the rate of 15 per hour.

Double-opposed keyways are cut with the same facility as are single ones, only a different form of work bushing or guide is used. As a general rule a double-opposed keyway broach has a tongue or guide running along its length on one side halfway between the rows of teeth, as shown in Fig. 4, Chapter I. This tongue fits a groove in the split work bushing or broach

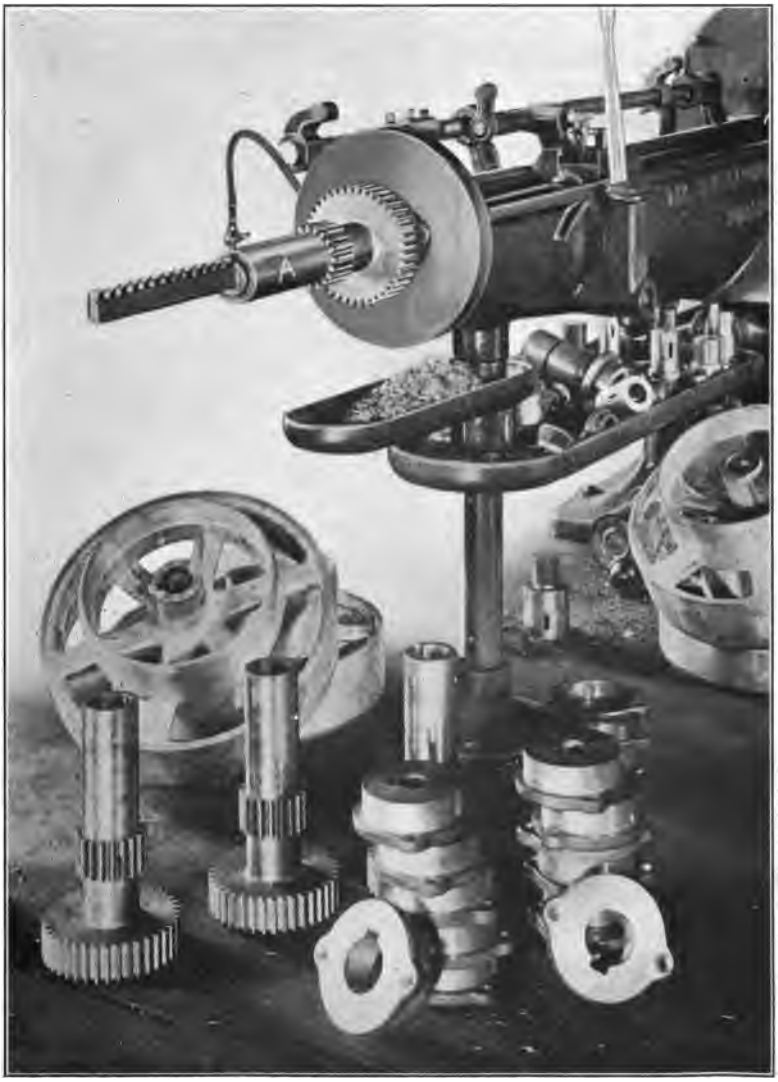


FIG. 21.—Machine set up for broaching keyways.

guide and keeps the broach cutting evenly on both edges as it is drawn through the work. In other cases, however, where the work will permit, the body of the broach is made to fit the bore of the work and no work bushing is used, the piece being butted against the face-plate or the end of the broach guide. This same plan of having the body of the broach fit the bore of the work is also sometimes used for single keyways.

Where two keyways of the same size are to be cut at right angles to each other, or quartering, it is common practice to cut the keyways in two operations with the same broach. For this purpose a work bushing slotted to correspond to the positions of the keyways is used. The work is put on and one keyway cut, then this keyway is moved around to coincide with the quartering slot of the bushing. A slightly tapered piece is then forced into the groove and keyway, locking the work into position for the next keyway. An illustration of this type of bushing is shown in the section on work holders.

Another and better way where the quantity of work will warrant, is to use a broach with two cutter bars. In this way the two keyways can be

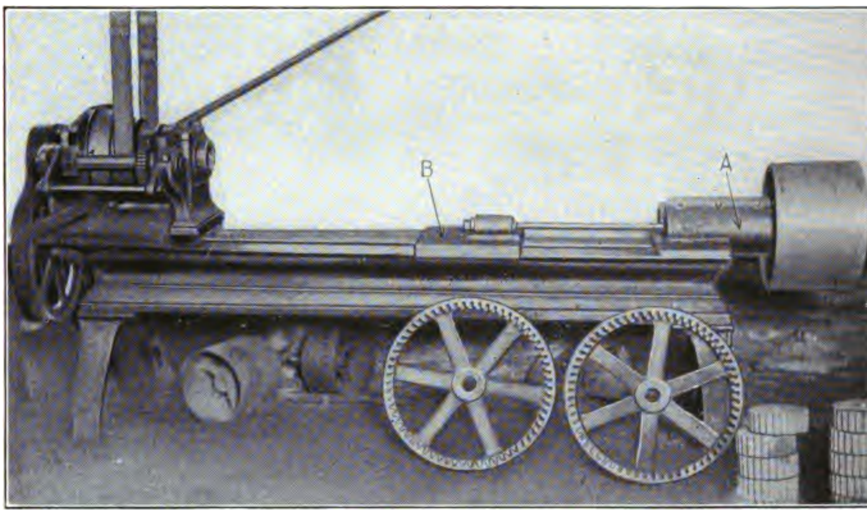


FIG. 22.—Broaching machine made from a lathe.

cut as quickly as one. This also holds true where more than two keyways are to be cut as broaches can be had with multiple cutters.

Still another way is to use an indexing fixture on the face-plate to hold the work, using a single cutter bar. This method is of course slower, but has the advantage of being adapted to various jobs where quantity is not the main object.

BROACHING MACHINE MADE FROM A LATHE

To show that good work may be done on a home made machine a broaching machine used in the shop of the Salem Iron Works, Winston-Salem, N. C., is shown in Fig. 22.

An old lathe, with a lead screw in the center of the bed, has been converted into a draw broaching machine by planing off the V's and fitting it up as shown. A heavy cast-iron bracket *A* has been bolted to the end to hold the work bushings. The sleeve of this bracket is split so that work bushings of different sizes can be easily clamped in place. The engraving shows a large drum in position for broaching out the keyway. The drawhead *B* consists of a cast-iron plate channeled to slide on the planed top of the lathe

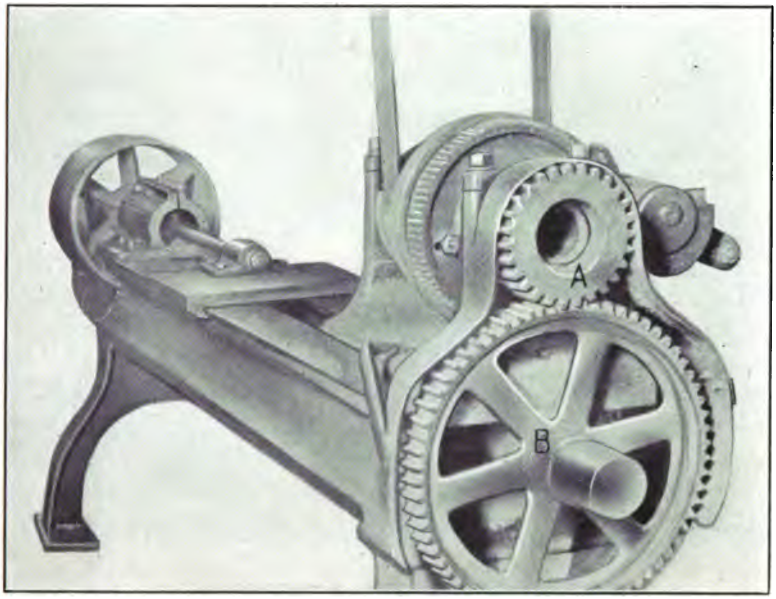


FIG. 23.—View of screw drive gears.

bed, having a nut underneath to fit the lead screw and a bracket on top to hold the end of the broach shank.

Different drawing speeds may be obtained by shifting the drive belt on the cone pulley, as well as by using the regular back gears, making six possible

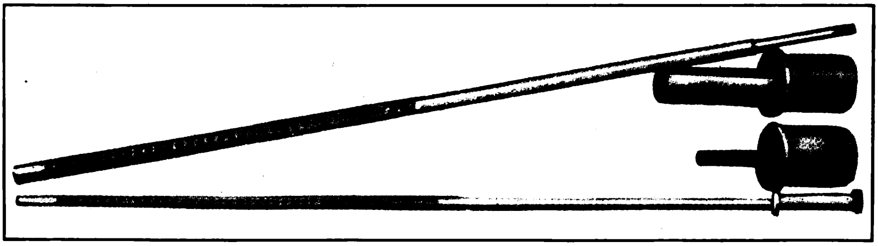


FIG. 24.—Two of the keyway broaches and bushings.

changes in all. The fact that keyways in both iron and steel castings are broached in this machine, makes the speed changes particularly convenient.

A better idea of the way the lead screw is driven from the spindle will be obtained from Fig. 23. A heavy pinion *A* is keyed to the rear end of the spindle, and this meshes with a heavy gear *B* on the lead screw; the ratio being about 2½ to 1.

The broaches used to cut the keyways are made of a bar of rectangular tool steel, in which the teeth are cut, set into a bar of machine steel. Two of these broaches and work bushings are shown in Fig. 24. The bars of the broaches are 6½ ft. long and the cutters extend 3 ft. The teeth are 1-in. pitch and increase in length 3/32 in. to the foot, or approximately 2½ thousandths each.

A BURTON KEYWAY MACHINE

The machine shown in Fig. 25 was made by the Burton Machine Co., Erie, Pa., and is the only one of this make the writer ever saw. It was in use in a shop visited in Canton, Ohio. It differs in many ways from others. It has two drawscrews geared together and set parallel with each other. The drawnut is made up of two half nuts set back to back and running between the two drawscrews. The drawbar or head to which the keyway cutter bar is attached, is drawn back between the two screws as the cut proceeds. Means are provided for automatically stopping or reversing the stroke. The work to be keywayed is set over a cone-shaped holder and is locked in place by means of a sliding block shown at the extreme right. This block slides on the bar shown which is notched on the side for a pawl carried on one side of the block. The machine complete probably weighed about 500 or 600 lb.

CUTTING A KEYWAY IN A TAPER HOLE

The method of holding the steering spindles of an automobile, while cutting a keyway in a taper hole in it, is shown in Fig. 26. A wedge-shaped plate, fastened to the front of the Lapointe broaching machine, has pins in it to locate the end of the spindle correctly when the taper hole is placed over the work bushing. The slant of this plate is just right to bring the upper part of the taper hole parallel with the travel of the broach when the spindle is set as shown. No holding clamps are necessary, as the draw of the broach holds the work securely. The two pins shown at the upper left-hand corner of the plate are used to locate the mate of the spindle forging being broached, as they are made right- and left-hand.

In connection with keyway broaching it may be well to state here that dovetail slots or keyways may be broached just as easily as the ordinary kind, in either straight or taper holes.

BROACHING SPIRAL KEYWAYS

Spiral keyways or grooves are also cut as easily as any other when once the machine is fixed for it. In most cases this necessitates the use of a revolving broach holder as well as a master broach guide grooved to correspond to the groove to be cut. In other cases, however, the broach does not rotate, but instead the work is placed on a revolving work holder or bushing,

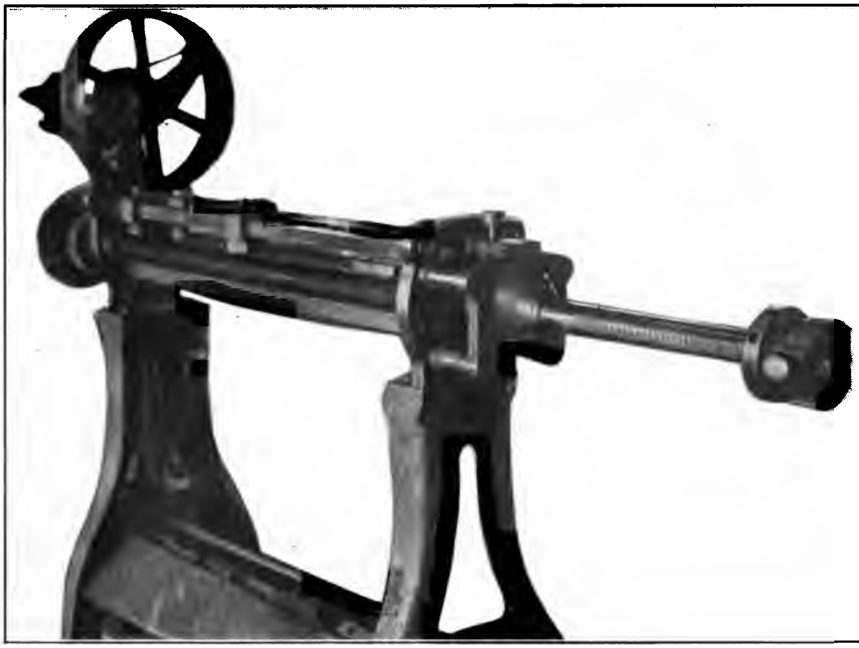


FIG. 25.—Burton keyway broaching machine.

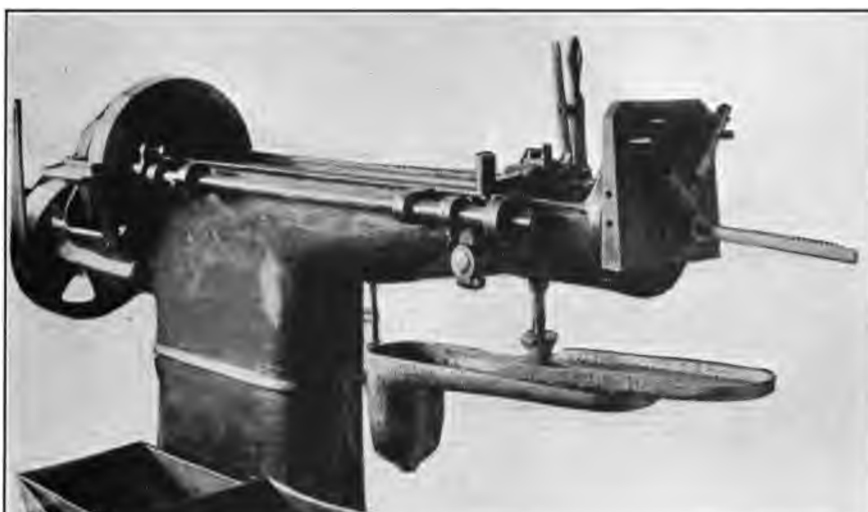


FIG. 26.—Broaching keyway in tapered hole.

ball bearing or otherwise, so as to rotate according to the spiral of the broach teeth.

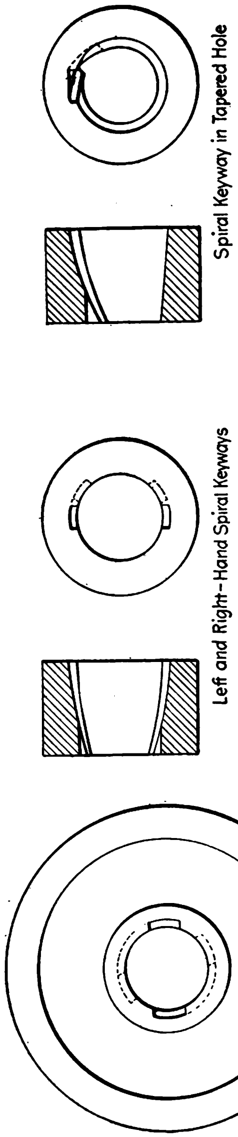


FIG. 27.—Broached spiral keyways.

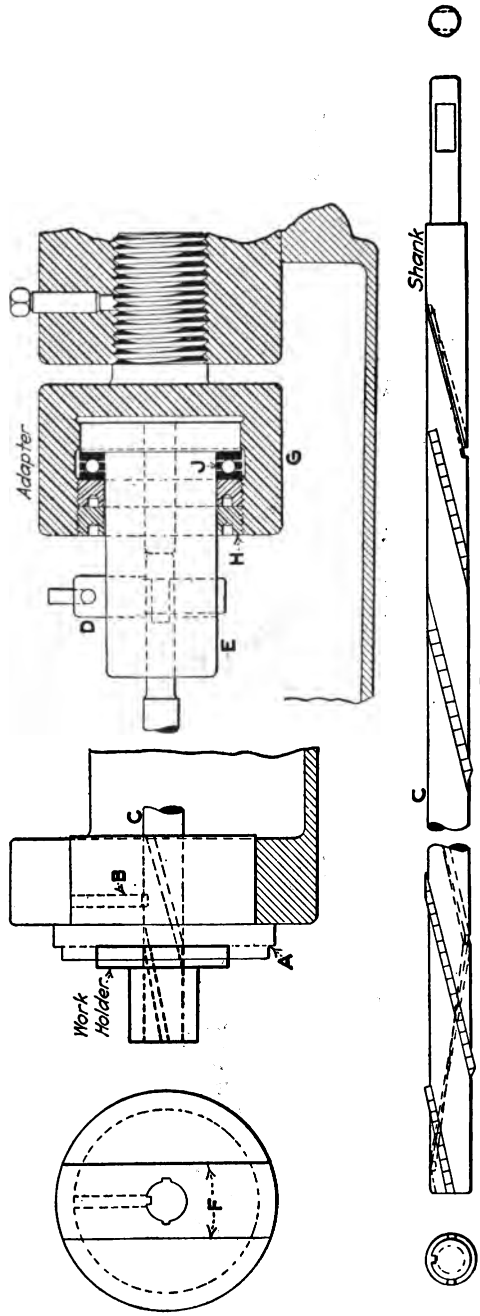


FIG. 28.—Fixtures used for broaching spiral keyways.

In an article published in the *American Machinist*, May 9, 1912, Frank J. Lapointe says:

Two ½-in. spiral keyways in a 1¼-in. hole are shown in Fig. 27. These pieces are about 3 in. long, and a production of about 25 to 35 per hour is obtained. The gears are very accurately broached in regard to the width of the keyway and lead of the spiral. This is a very high production for such a piece. There are, no doubt, many places where similar pieces could, but have not been, used because the piece was considered too expensive. With the modern broaching machine and with properly designed broaches, the cost of machining a piece of this nature is very little indeed.

Two spiral keyways, one left- and one right-hand, are seen. The piece shown can usually be done in one operation depending upon the length of the work and material to be cut. It is accomplished by the use of a special double spiral broach which cuts the two keyways at one stroke of the machine. This assures proper indexing of the two keyways with relation to each other.

A spiral keyway in a tapered hole is shown. This can also be done in one operation, and while it is very rare that a keyway of this shape would be called for, this only gives an illustration of another peculiar piece that can be done with properly designed broaches. This piece can be broached very accurately as regards lead of spiral and width of keyway, but there is a slight defect as to the depth owing to the taper of the hole. This being so slight, in most cases it is negligible.

In the March 16, 1916, issue of the *American Machinist*, M. Henry writes:

A job accomplished on a standard type of broaching machine is shown in Fig. 28, the work being small and made in large quantities with two spiral keyways cut in it. The piece is mounted in the bushing at *A*, while two broaches are drawn through it—namely, roughing and finishing. The arrangement of the tools for this operation is as follows: In the bushing *A* is placed the guide pin *B*. The shank of the broach *C*, with the work slipped over it, is pushed through the work bushing and gripped by the pin *D* in the broach holder *E*. The work is now held by hand against the work holder and is prevented from turning by the sides *F*. The machine is started and draws the broach through the work, the spiral twist being obtained as the groove necessarily follows the line of the pin.

As there is no means of allowing the broach to twist in these machines, an adapter is provided. It consists of the broach holder *E* in the adapter *G*, two check nuts *H* and a ball bearing *J*. All these parts are mounted on the drawbar of the machine in a manner similar to that employed for holding broaches on ordinary broaching machines.

Fig. 29 is an illustration taken from the catalog of the Lapointe Machine Tool Co., Hudson, Mass., to show the broaching of four spiral keyways at once. Two broaches are used, a roughing and a finishing. The roughing broach is shown in the machine and the finishing broach lying in the pan. An end view of a piece of the work is shown next to the finishing broach.

BROACHING ROUND HOLES

Next to keyway work, the broaching of round holes is probably the most familiar to the average machinist. The great variety of work for which it

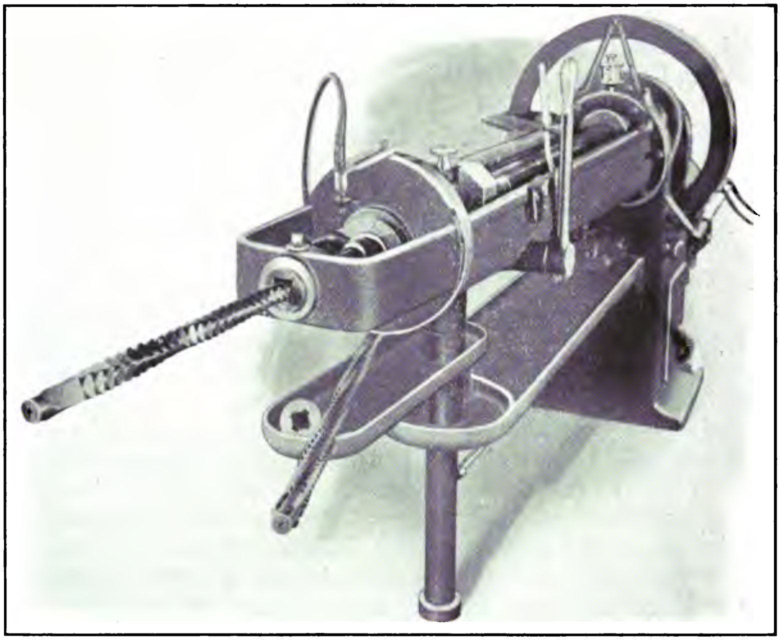


FIG. 29.—Machine set up for broaching four spiral keyways.

FIG. 30.—Finishing a round hole in a steel casting

is adapted is almost unlimited. On some classes of work, round-broaching is much preferred to finish-reaming. In a large number of ordinary jobs,

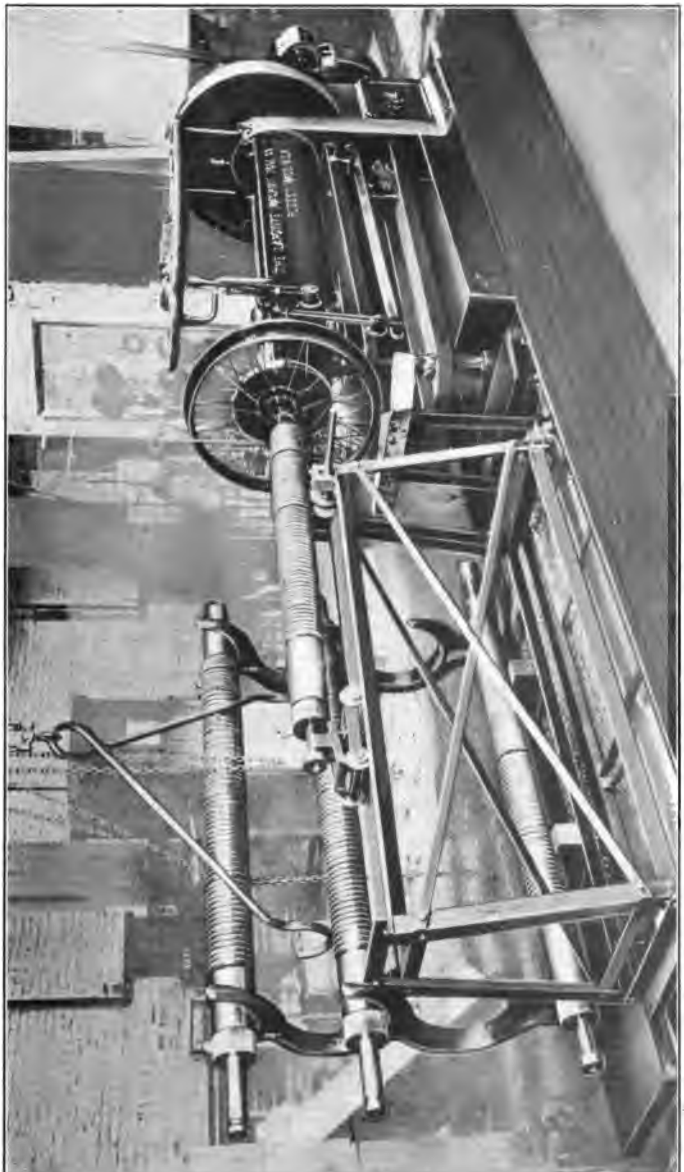


FIG. 31.—Broaching automobile wheel hubs.

the work is drilled close to size and then finished with a single broach. Other jobs require two or more broaches in order to obtain the required accuracy.

A round-broaching job is shown at *A*, Fig. 30. This is a steel casting which is located by means of a small plate screwed to the face plate of the machine. After a piece is broached it is removed, the broach run out and disconnected, another piece put in place, the broach run in and connected to the drawhead and then the broach is pulled through the hole. The steel castings were so hard and tough that reamers were of no use at all. The hole is 1¼ in. in diameter by about 3½ in. deep. The broach produces about 30 per hour.

An unusually heavy broaching job done in the Rudge-Whitworth shops is shown in Fig. 31. It is especially interesting on account of the size of the broaches, the method of handling them and the way they are supported on the overhang. The machine used is a No. 4 Lapointe. The broaches shown are 4¾ in. in diameter, and made up of case-hardened steel disks strung on a specially heat-treated nickel steel bar. By using the chain hoist and hooks, the operator has little trouble placing or removing the broaches from the wheeled carriers and then connecting or disconnecting the drawhead.

BROACHING AND BURNISHING BEARINGS

The method of broaching and burnishing bearings, shown in Fig. 32, was first obtained in the shop of the Locomobile Co., Bridgeport, Conn. These bearings are of composition metal and the broach is made to finish a 1⅞-in. hole and has 12 teeth which increase in size by 0.0005 in. each from first to last and the swage or burnisher *A* is 0.005 larger than the last tooth of the broach, being tapered slightly at the start, so that it doesn't shear the bearing. The bearings thus finished are very true and do not need to be touched with reamer or scraper. The lubricant used is prime lard oil and the engineer's figures show that it takes from 5 to 6 hp. to run the machine and a pull of 5000 or 6000 lb. to draw the broach through. The pressure of the burnishing part of the broach on the bearings is so great that some other means than the two regulation screws had to be devised to keep the parts from spreading, which is done by using the jig shown in Fig. 33, which consists of a heavy steel ring or box, into which the end of the connecting rod is set and the setscrews shown used to keep the bearing caps from being forced apart. This jig, of course, rests against the head of the broaching machine when in use, as shown in the first halftone.

ANOTHER BEARING BROACH

The broaches shown in Fig. 34 were made for the Marathon Motor Works, Nashville, Tenn., by the Lapointe Machine Tool Co. The white bronze bearings of the connecting rods and the disk *A* are broached with these tools. The blank spaces between the teeth both compress the metal and act as truing guides for the cutting teeth. The spiral grooves assist in keeping the parts lubricated during the process, lard oil being used. There is about 0.010 in. difference in size from one end of the broach to the other. The blank spaces are slightly tapered on the entering end to prevent bunging up the metal of the bearing on the draw. These broaches do entirely

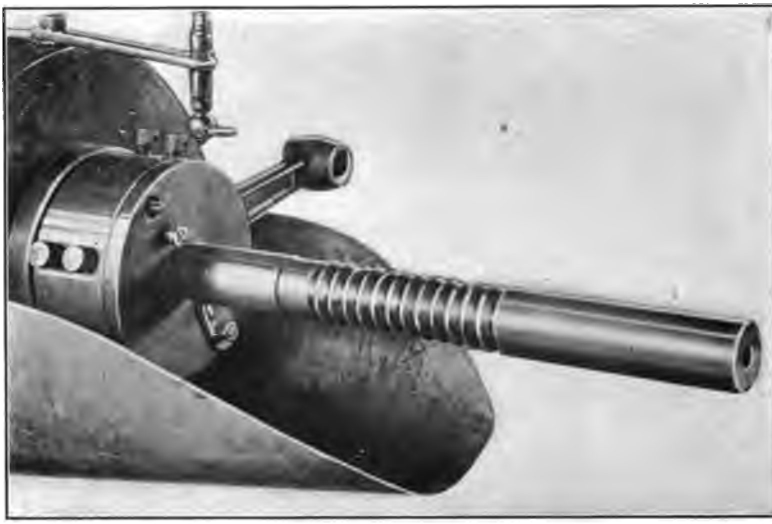


FIG. 32.—A sizing and burnishing broach.

away with reaming and are much faster working and give just as good results for when finishing a hole by reaming, the cutting edge of each reamer blade

FIG. 33.—Holder used to prevent spreading.

travels a distance approximately equal to the circumference of the hole multiplied by the number of turns made by the reamer in passing through the work. In the case of a round broach, the distance traversed by any point on the broach in machining a hole is equal to the length of the work; hence, it can easily be seen that broaching is a much faster operation than reaming, especially when the broach has a cutting speed of at least 4 ft.

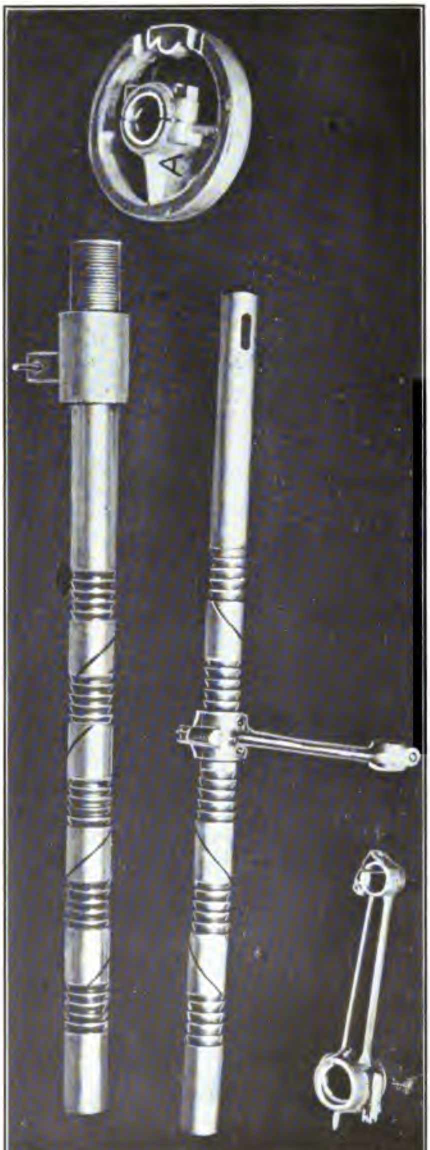


FIG. 34.—Another bearing broach.

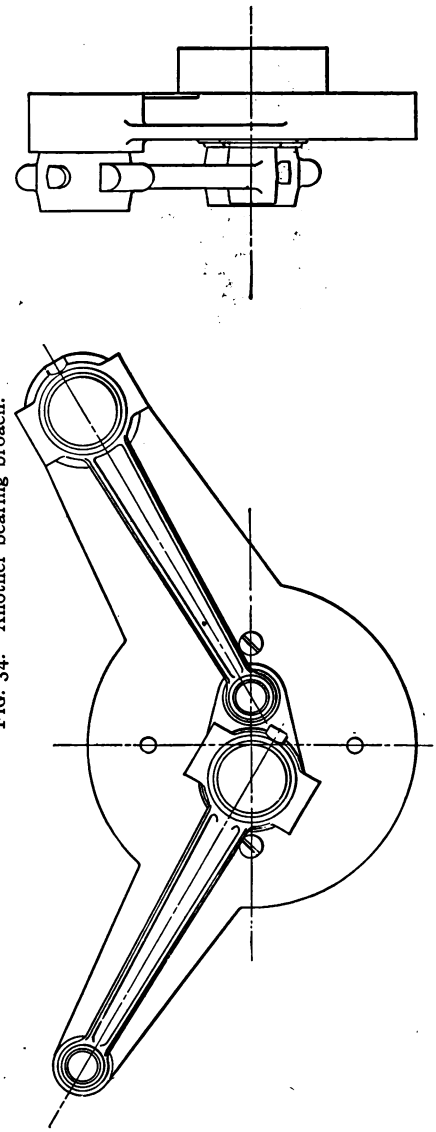


FIG. 35.—Method of finishing a rod at each draw.

per min.; moreover, the broach will maintain its size for a longer period than a solid reamer, because the finishing end of the broach has a number of teeth of the same diameter, and as these only take very light finishing cuts they are subjected to very little wear. Even an adjustable reamer has no longer life than a well-made round broach.

It has been demonstrated that the broaching of hard chrome-nickel steel, such as is used in automobile work, is a much cheaper process than reaming. A typical job is shown in Fig. 35, which illustrates two connecting-rods and their broaching fixture. The small end of one rod and the large end of the other are broached simultaneously on a regular No. 3, Lapointe machine. In this way, one complete rod is finished for every stroke of the machine. The fixture is not absolutely necessary, but adds considerably to the production. These connecting-rods are first drilled to the size of the broach shank or to a diameter of from 0.015 to 0.030 in. under the required size. They are then finished by broaching, thus eliminating both machine and hand-reaming. After the rods have been broached, the large end is split and the lining bushing for the large end is inserted. The bushing for the small end is pressed into the rod. These bearings or bushings are then broached, and the finish obtained can only be duplicated by scraping, although broaching is, of course, much cheaper, and the metal is compressed somewhat, thus giving the bearing a hard, glazed surface that resists wear.

The broaches used on this work are of the same type as those shown in Fig. 34 and are made up with plain round sections for the purpose of keeping the broach from "running" or "crawling," as it is essential that the center-to-center distance of these rods be kept fairly accurate. By introducing plain blanks or sections between the teeth, the broach is kept properly aligned with the hole, because there is always some portion of the blank section in the work while some of the teeth are cutting.

When using these broaches in cast iron, a soap cutting compound is used, as this gives the broached surface a highly polished finish. For chrome-nickel steel, a good grade of cutting oil will give satisfactory results. On some work, no drilling whatever is done prior to broaching, and very often only one broach is used; but if the work is longer than, say 2 in., a roughing broach usually precedes the finishing broach. Of course, broaching from the rough can only be done when the broaching operation comes first, as otherwise the broach would follow the rough hole and, consequently, the finished hole would be out of true with any other surfaces which might be machined before broaching.

In discussing the broaching of bronze castings in their shop in Hudson, Mass., Frank J. Lapointe says: These castings have a round hole 2 in. in diameter and 4½ in. long. We allow ⅛-in. stock to be removed, or 1/16 in. on a side, the hole being cored ⅛ in. smaller than the finished size. When we bored and reamed these, we allowed ¼ in. and the time was about 10 min. each. We broach them in 1¼ min. and do not have to bother to clamp or chuck the work in any way. The finish is better than by reaming. In reaming hard bronze it is difficult to overcome the chattering and waving of the reamer, but the broach properly made does away with this difficulty. Of course the results obtained by broaching depend on the broach itself. Our broaches are ground all over after hardening and are backed off at the proper angle to give them a nice cutting edge. The teeth are nicked to break the chips on the heavy cutting part of the broach, but the last six or eight teeth that do the sizing are not nicked. Following the last six or eight sizing teeth is a short pilot which supports and guides the broach. One very important thing in broaching round holes is the proper spacing of the broach teeth. At no time must there be less than three teeth in the work, in order to properly support the broach; if the teeth were so coarse that only one tooth was cutting while another was entering, it would give the broach a slight movement, causing waves in the work. The broach must always be made up with differential spacing of the teeth. If the teeth are all evenly spaced, as a rule very unsatisfactory results will be obtained.

When making broaches a number of things must be taken into consideration, viz., material to be cut, length of work, amount of stock to be removed on the outside, and the shape of the work, so that the proper support can be provided. The length of the broach depends entirely on the metal to be removed. Of course in cases where the broaching operation is for sizing, a short broach is used, usually having about 10 in. of cutting edge. If the broach is to remove 1/8 in. of stock, the length may vary from 28 to 40 in., depending on the length of the work.

The use of four broaches at once on a J. N. Lapointe two-spindle machine is shown in Fig. 36. The broaches used were made by the H. J. Walker Co., Cleveland, out of carbon steel, and were hardened by the Vincent Steel Process Co., Detroit, Mich. The holes finished are 2 3/16 in. in diameter and 600 pieces are finished per day. It is claimed that these broaches have the speed and nearly the length of life of those made of high-speed steel.

BROACHING SQUARE HOLES

To the man doing broaching work there is more than one kind of "square" hole. There is the square hole with round corners but straight sides; the hole with round corners and the sides only partly straight, as the round of the drilled or reamed hole is not entirely cut away; and other variations of these; and last and most rare, the perfectly squared hole, with sharp corners. For commercial purposes, the hole with fairly well cleaned-up sides and round corners is plenty good enough as a rule, and usually can be finished from the drilled hole at one pass, in almost any grade of metal.

A bevel gear blank being broached out is shown in Fig. 37. This is done in the shop of Brown & Sharpe on a Knowles type of machine. The metal is a particularly tough grade and several broaches are used to obtain the finish and accuracy needed for their work. The blank is located on the face-plate by means of a ring and is held securely in place by two strap clamps as shown. Speed is not sought after in this case as accuracy is the principal aim.

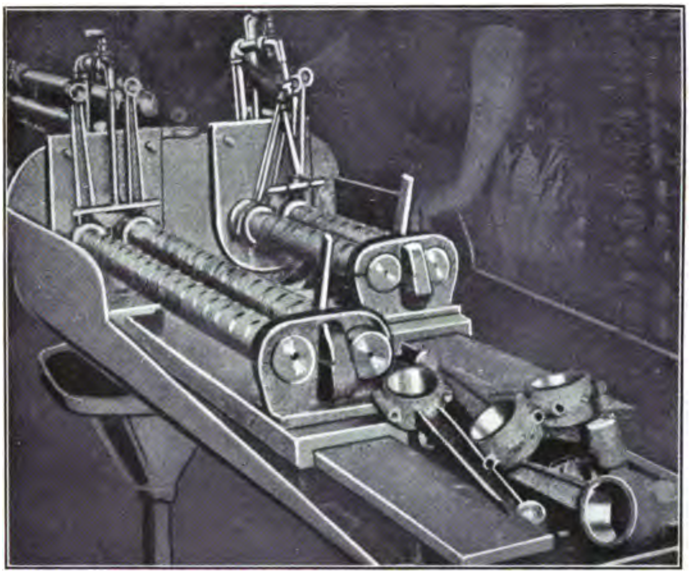


FIG. 36.—Broaching rods on a two-spindle machine.

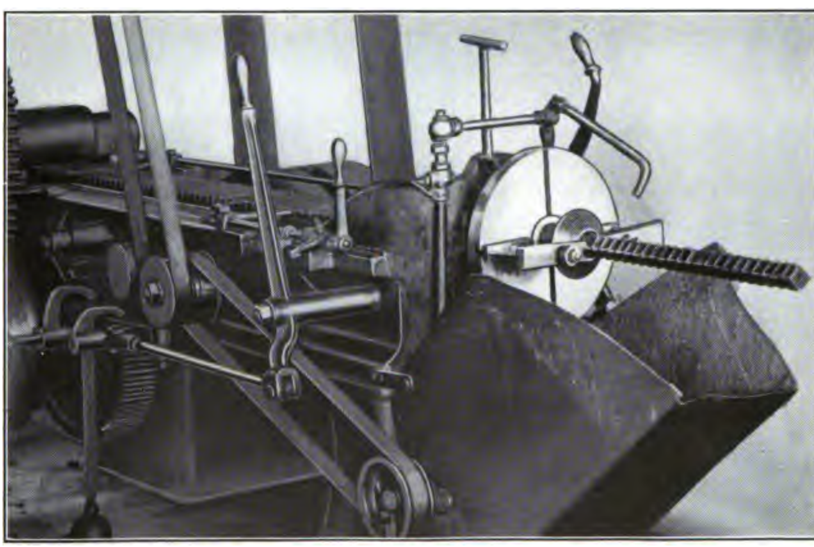


FIG. 37.—Broaching a square hole in gear blank.

BROACHING TAPERED SQUARE HOLES

In broaching tapered square holes, a broach like the one indicated in Fig. 38 is used, and one corner broached at a time. After one corner is

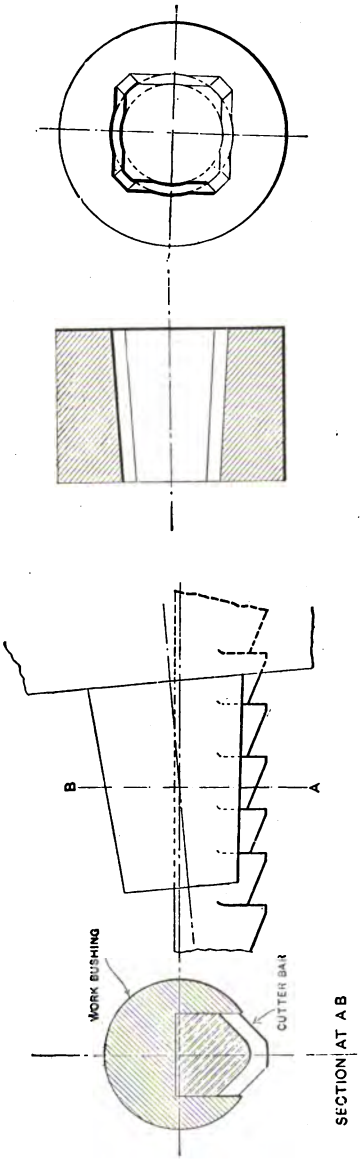


FIG. 38.—Sectional view of cutter bar in work bushing and shape of tapered square hole when finished.

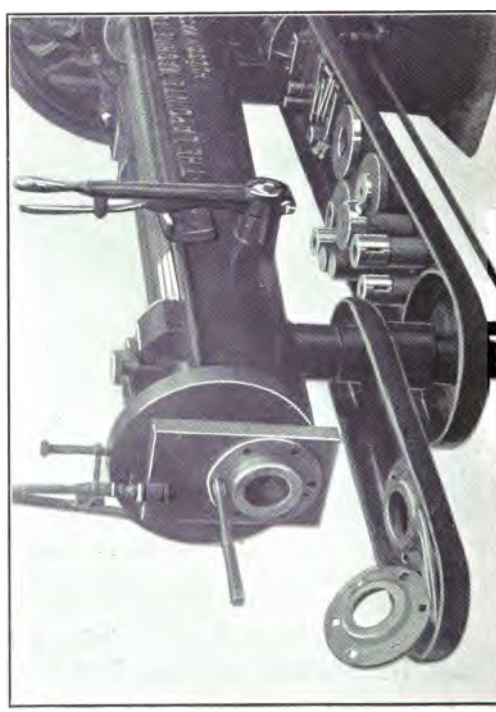


FIG. 39A.—Broaching square holes in jig.

FIG. 39B.—Broach, holder and cutter.

broached, the work is indexed a quarter turn and the next corner is broached. The work bushing as shown is tilted according to the taper of the hole being broached, in practically the same way as for broaching a keyway in a tapered hole, which has already been described. In no way, other than by broaching, could holes of this character be machined on an economical commercial basis, and accurate results be obtained.

BROACHING SQUARE HOLES IN A JIG

In a short article in the *American Machinist*, T. B. Greene says:

An interesting operation is shown in Fig. 39*A*. It consists of a motor-car hub detail in the shape of a flange 3/16 in. thick with six 7/16 in. holes, which have to be squared out to 0.468 in. The centers of the holes have to be kept good, so that a jig is necessary for the broaching operation which follows the jig-drilling operation.

The jig consists of a cast-iron plate bored to receive the check on the hub flange and also to take an adapter, fitting the machine table. These holes are bored to correct centers. Six holes are drilled and counterbored in the plate with the same centers and spacing as the work. This is to allow the passage of the broach and also to give clearance for burrs thrown up on the back of the hole after broaching.

The broach holder in the machine is set true with the holes in the jig by means of a test bar, and the work is brought into alignment by the plain guide on the broach. The broach is made of a special steel, which lends itself to straightening easily after hardening, and is ground all over.

The teeth are 9/64 pitch and remove about 0.002 in. per tooth. Two flats are milled on the shank of the broach to take a U-shaped cotter for pulling purposes, as shown in Fig. 39*B*. These flats are in correct relation to the sides of the broach, so that it may be lined up from the flats to get the sides of the square hole true with the center line of the work.

The work is turned out at the rate of 10 to 12 an hour, *i.e.*, 60 to 70 holes per hour. Over 2000 holes have been done without the broach requiring sharpening. Roughly speaking, it is eight times quicker than filing and finishing with a sizing drift, which was the method used for finishing these holes before broaching was adopted.

BROACHING RECTANGULAR HOLES

The next job shown in Fig. 40, is the broaching out of rectangular holes in connecting rods. This is representative of work of this class. The holes broached as shown are 4 by 6 in. and 2 in. thick. The rods are rough drop forgings and about 25 holes are broached per hour.

In Fig. 41 is shown a No. 4 J. N. Lapointe machine rigged up for broaching out vise bodies. The hole broached is 4½ by 6 in. The piece itself weighs about 90 lb. The broach used in broaching this work weighs 265 lb. Owing to its enormous weight it is arranged with shank on the rear end to telescope into the support bracket, which is firmly fastened to the table, so that when the broach is disconnected from the machine, it is supported in the bracket, and can be conveniently rotated to clean the chips out.

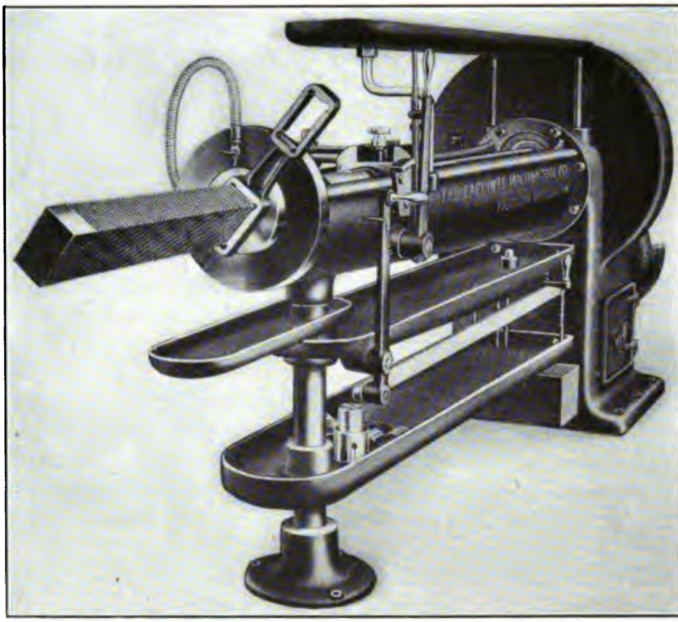


FIG. 40.—Broaching a connecting rod.

After the vise jaw is slipped on the end of the broach for the operation, the machine is reversed, bringing the connecting bushing into the broach,

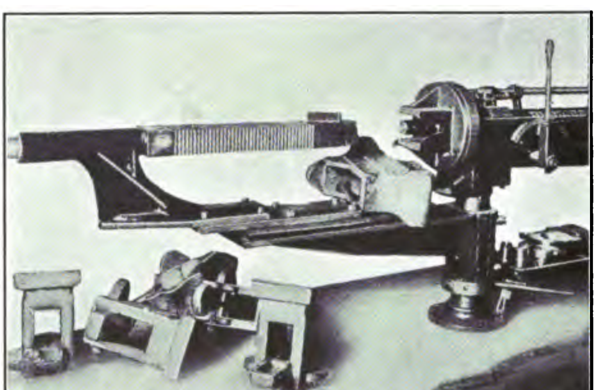


FIG. 41.—Broaching out vise bodies.

and by means of a key the broach is connected, and the machine started for the operation, and before the shank leaves the support bracket the pressure is sufficient to hold the broach in position without any further support of the bracket. This makes the machine very convenient and handy for handling such heavy broaching tools, and has been found most advantageous.

ANOTHER VISE JOB

The making of the Prentiss bench vise, which has been known to mechanics for many years, contains some interesting processes as carried on by the Bagley & Sewall Co., Watertown, N. Y.

The tools used in broaching the bodies are interesting both on account of their size and the way in which they are built up. They are shown in Fig. 42. Arranged on the bench behind the broaching machine are a number

FIG. 42.—A special machine for vise work.

of vise bodies, most of them of the plain solid-jaw type, with the broaches in place, giving something of an idea of the range of sizes.

The body to be broached is supported on the bracket at the end of the machine, as shown, this being adjustable for various sizes, so as to easily bring the work to the proper height. In the larger sizes these broaches are built up of tool-steel toothed plates, on soft-steel bodies, as can be seen. It will also be noted that there are small sections inserted on some of the broaches, on top, just where they leave the work. This is especially noticeable on the one in the machine. The use of sections inserted like this makes it easy to keep the corners sharp, as a new piece may be put in or the old piece sharpened without working over the whole broach. Broken sections may also be replaced in this way, without making an entirely new plate.

Another interesting feature is the method of locking the broaches to the draw spindle by means of a pair of hooked jaws, which fit over the rounded and notched head of the broach. This will be easily understood by closely inspecting the ends of the broaches in the front of the machine. This allows very rapid handling of the broaches, it being unnecessary to drive out keys as usual. This method of locking has been in successful operation at this plant for a long time.

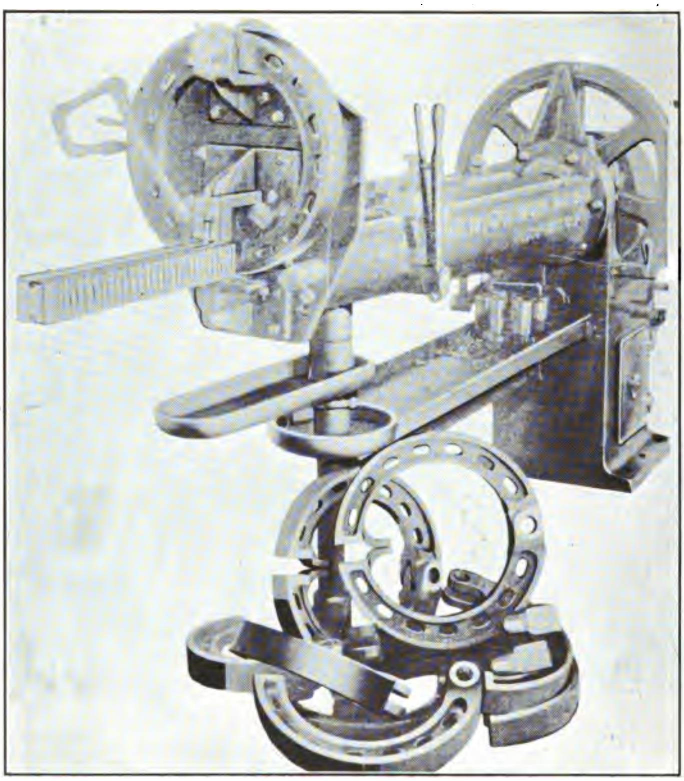


FIG. 43.—Finishing ends of expanding rings.

FINISHING ENDS OF EXPANDING RINGS

Special attention is called to the method of finishing the ends of expansion brake rings shown in Fig. 43. The fixture was made by the Lapointe Machine Tool Co. and is so made that the work is held securely and truly, yet is easily removed or put in. A pin at the top goes through a reamed hole in the ring while below two setscrews in posts locate and lock each end of the ring on either side of the broach, so that they cannot spring away from the cut. The broach is channeled out on top and bottom and these grooves are run over steel guides set into brackets on the face-plate of the machine. By this method the broach is guided straight and true as it is drawn through the work.

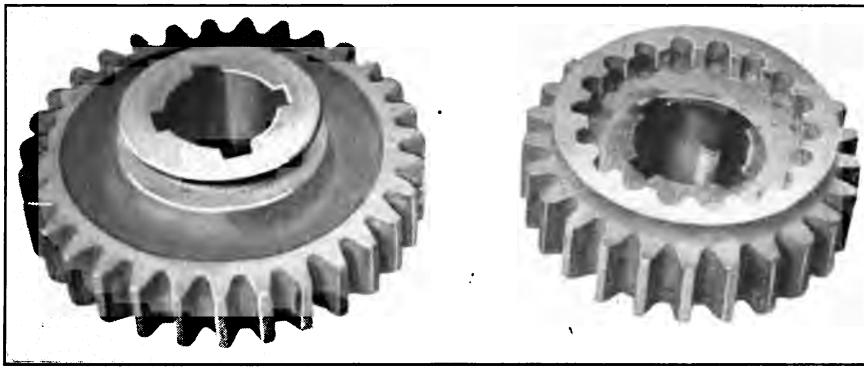


FIG. 44.—Four splined steel gears.

BROACHING FOUR SPLINE HOLES

The Bullard Machine Tool Co., Bridgeport, Conn., broach four spline holes in some gears made by them for outside parties. Fig. 44 shows two of the steel gears, and a gear being broached is shown in Fig. 45. The teeth

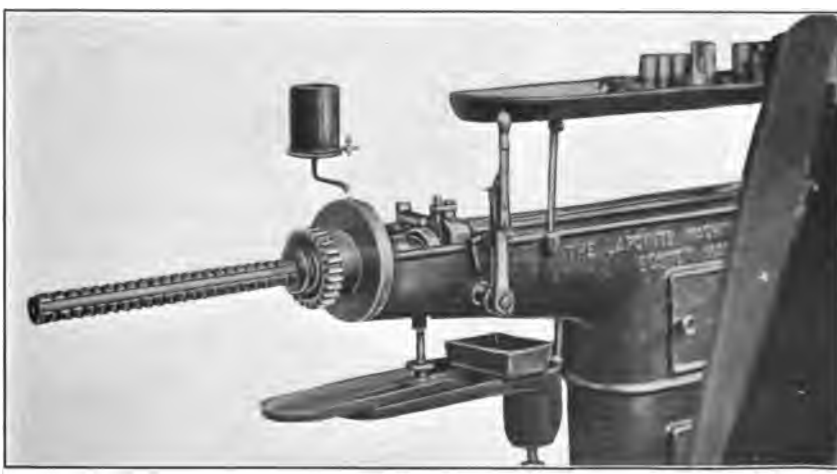


FIG. 45.—Broaching splines in gears.

of the broach for this particular job are ¾ in. pitch and 0.44 in. in width. The lands are 0.07 in. wide, with a 5-deg. slope. Back of the land, the slope is 30 deg. to the channel at the base of the tooth. This channel is 5/16 in. wide and somewhat flattened on the bottom, having a fillet of 1/16 in.

radius on each side of the bottom, and so made as to give a 3-deg. undercut to the tooth. The undercut and smooth fillet give the steel chips a nice curl.

The outside of the broach is 2.192 in. in diameter at its largest part, and the broach, 48 in. in length, is made from a bar of 2⅜ in. steel, cut to length, centered, and the scale turned off. The piece is then annealed, after which it is turned and milled to shape, allowing 0.024 in. for grinding. After hardening, the broach is straightened on centers to within 0.005 in. of true and then ground to size.

This job is typical of splining work, whether of four or a dozen splines. Solid keys or feathers are also cut in the same manner with equal facility.

A DOUBLE-END BROACHING MACHINE

In an article in the *American Machinist*, Fred. H. Colvin describes a big double-end broaching machine built and used in the shop of the Winton Motor Co., Cleveland, Ohio. After experimenting with quick returns for the screw which pulls the broach, it was decided to build a double-acting machine so that a constant cutting speed could be maintained and work be done continuously. This machine is shown in Fig. 46.

After the operator starts a broach through a piece of work at one end, he goes to the other end of the machine and repeats the operation, there being ample time to do this during the cut; in this way there is always a broach at work, even though each end, considered by itself, runs back idle as in the usual machine. The broaches are held by a simple clamp, made in two parts, and held in place by a sliding collar.

The principle of the machine is simplicity itself, as a single drawnut is used, set in the middle of the machine bed between guide brackets, and revolved in either direction by means of a worm and worm wheel driven from a pulley at the side. Two belt speeds are available by using the two-step cone. By setting and driving the screw in this way, a screw only about the length needed for a single machine is necessary. Several of these machines are in use in this shop, and they are built powerful enough for any broaching job they may have in the manufacturing line.

BROACHING AN INTERNAL CAM

We now come to some of the more specialized forms of broaching and show a few jobs that will give something of an idea of what can really be done where the quantity desired will warrant. Fig. 47 shows the broaching of a gear which has four cam-like surfaces around the central hole. The gear is steel 1¼ in. thick. The cylindrical hole in it is 4½ in. in diameter. The width of the cam surfaces is about 1$^{15}/_{16}$ in. by about $^{11}/_{16}$ in. at the deepest part. The gear *A* is mounted on the stub *B* which is provided with a slot for the broach. Indexing is taken care of by the index pin *C* entering a tooth space. From six to seven finish-broached gears are produced per hour.

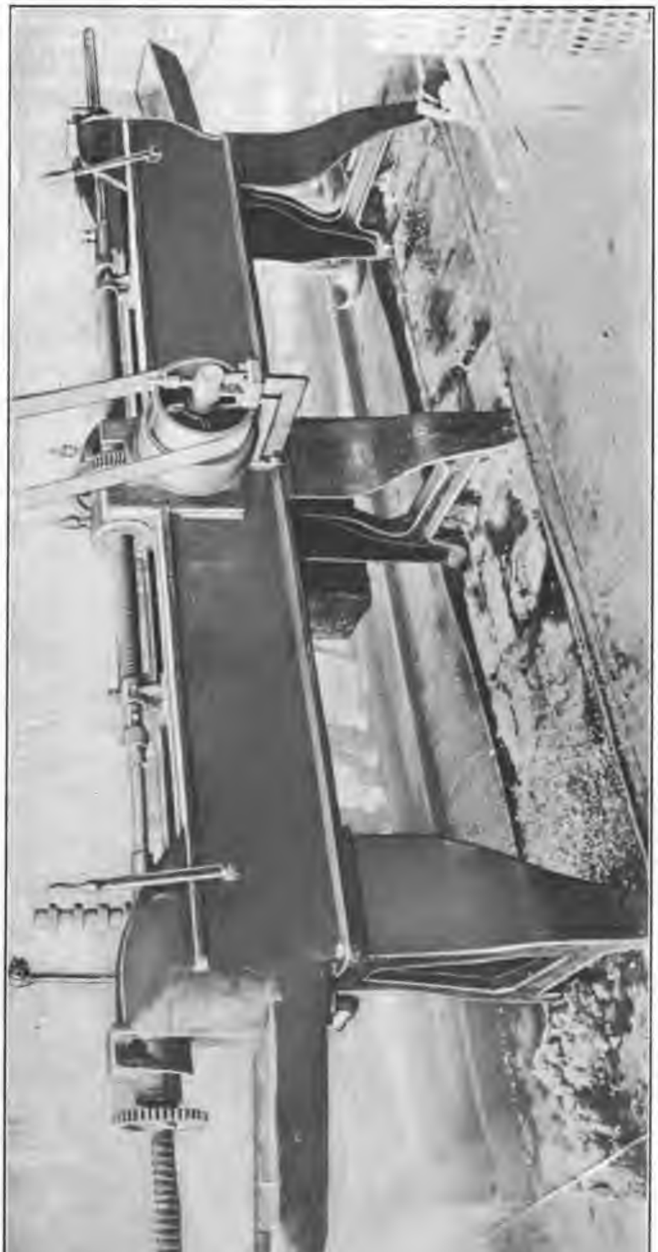


Fig. 46.—A double-end broaching machine.[1]

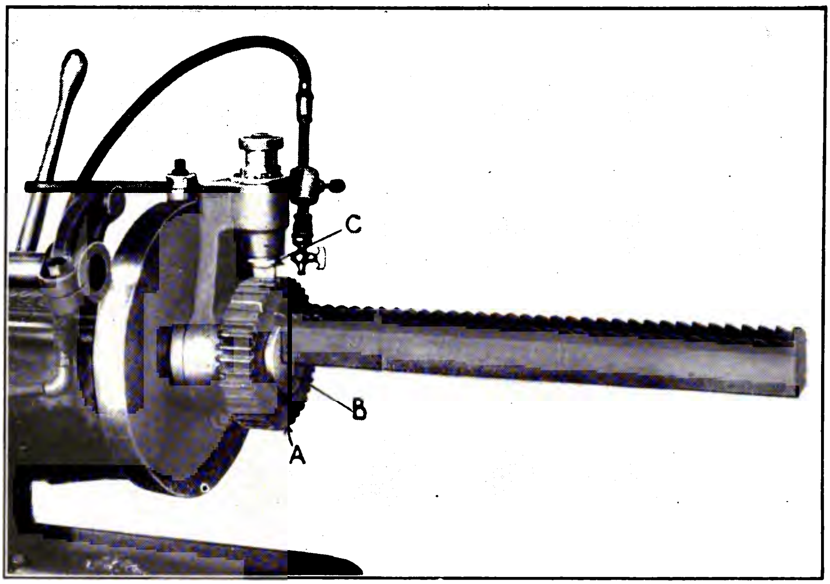


FIG. 47.—Broaching an internal cam.

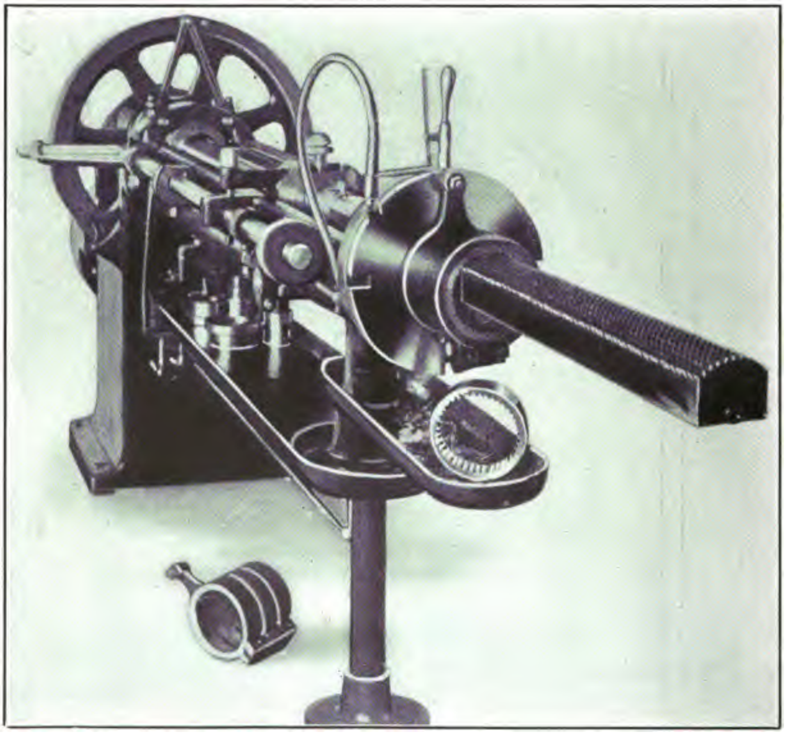


FIG. 48.—Cutting internal ratchet teeth.

The cutting of internal ratchet teeth is illustrated in Fig. 48. This is done on a Lapointe machine and the job consists of cutting 40 ratchet teeth around the inside of a nickel-steel piece, like the one shown lying in the pan under the face plate of the machine. The bore of these blanks is 4½ in. The blanks are held three at a time, in a special indexing fixture, and finished in four draws at the rate of 30 complete ratchets an hour, within a limit of 0.002 in.

The blanks to be broached, are held in clamping fixtures, one of which is shown on the machine and another on the floor. These clamps have an arm on them carrying a locating pin, which fits notches in the rim of a plate fastened to the face-plate, as shown. A work bushing serves to locate the clamp and guide the broach. When one cut has been taken, the broach is run out and the arm of the clamp is moved around, so that it fits into the next notch of the index plate, and then another cut is taken, and so on till completed. Two clamping collars are used, so that one may be loaded while the machine is broaching a set of blanks. There are 12 rows of teeth in the broach, so that it cuts ten teeth at a time, and overlaps one on each side.

The next job shown in Fig. 49 is the squaring of the inside corners of a chase used on a Hoe press. The chase is set on the adjusting pads *A* and *B*, over the broach guide *F* and is locked in place by means of the screw *D* and small handwheel *C* which operates a slide with a *V*-cut in the end where it contacts with the corner of the chase. As the broach *E* is drawn through the corners are machined out sharp and clean and true with the outside finished edges of the piece.

BROACHING A 22-IN. INTERNAL GEAR

The illustration, Fig. 50, shows an interesting development of broaching as a manufacturing operation. This is a No. 4 machine, built by the J. N. Lapointe Co., New London, Conn., the gear being mounted on a large rotating indexing fixture to which the supporting bracket for the broach is rigidly connected. This indexing ring has three handles so as to be easily turned, the indexing teeth being cut on the outside and the locating pin placed directly above the broach.

This gear, which is a drive for a heavy auto truck, is 22-in. pitch diameter, 3 diametral pitch and about 2½ in. thick, the material being 45-point carbon steel with a small proportion of nickel added.

There are two broaches—one for roughing and the other for finishing—these being made from one solid piece of steel and for working on four teeth at a time. They can be adjusted with regard to the work by means of a tapered key on which they slide. The first broach roughs out the gear; then, without dismounting this, the finishing broach is put into place and completes the gear. The time for machining is about one-half that of any other method. The pinion, which is 6 in. in diameter, is shown at the bottom of the gear. The pull on the broach is given as 60,000 lb.

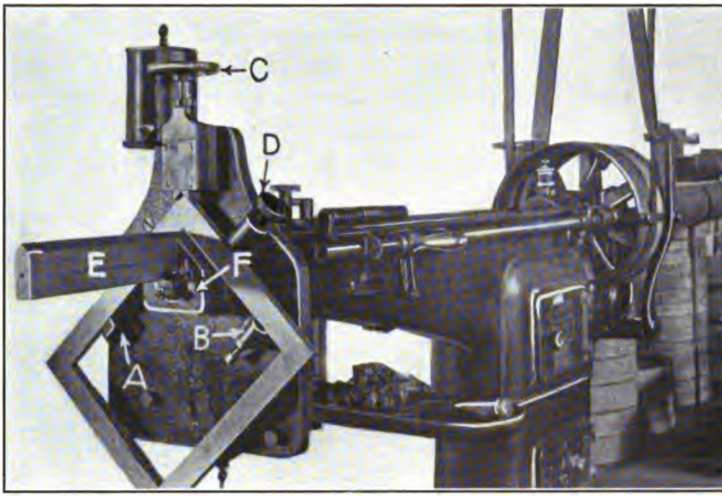


FIG. 49.—Broaching the inside corners of a chase.

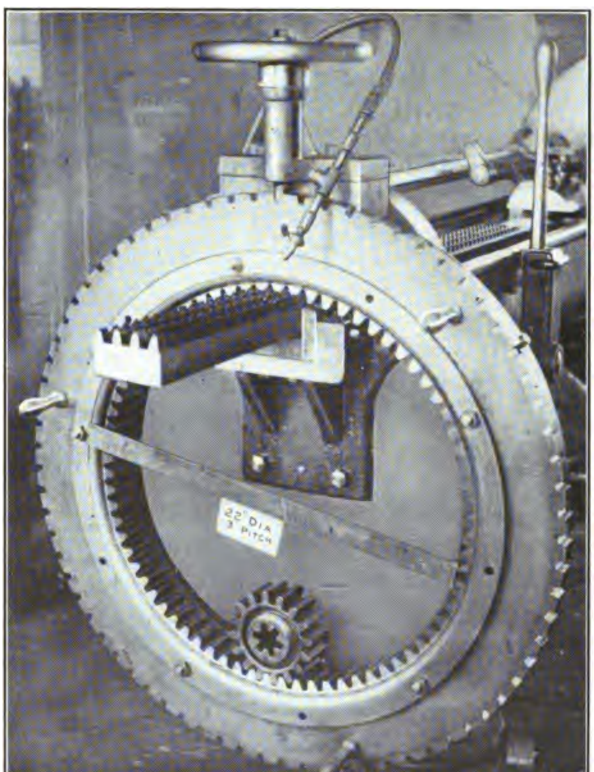


FIG. 50.—Broaching a 22-in. internal gear.

BROACHING SEVERAL PIECES AT ONCE

While a number of those jobs already shown are broached in multiple a few more special ones are shown here. Fig. 51 is unusual since the pieces

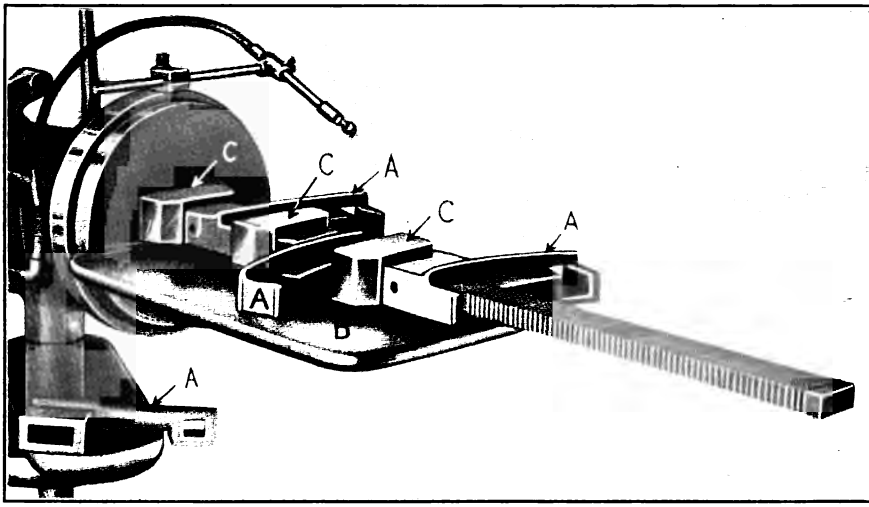


FIG. 51.—Broaching three irregular pieces at once.

are irregular in shape and would ordinarily be thought impractical for multiple work. However, by the arrangement shown, three of these cast-iron

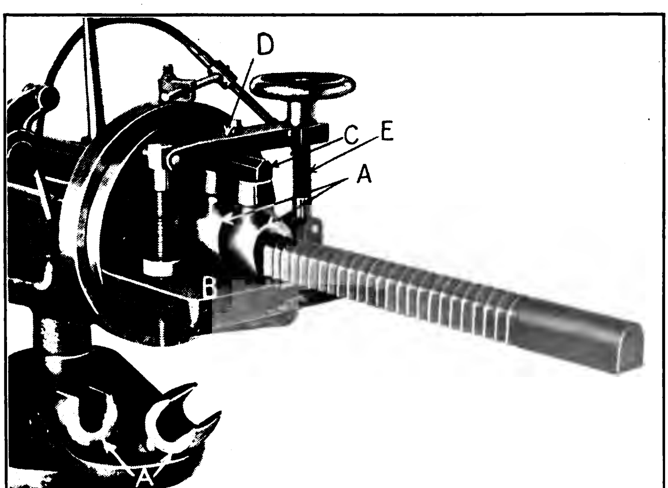


FIG. 52.—Broaching textile machine poppet heads.

pieces are broached at once. The pieces are indicated at *A–A–A*. They are cast-iron brackets used in textile machinery. They are made right and left and have two rectangular holes in them, the larger of which is 15/16 by 2 1/4 in. Three pieces are broached at a time in the fixture *B*, which is provided with the concave lugs *C* to take the thrust. These pieces were formerly filed out, and the time on them was from 10 to 20 min. each depending on the condition of the cored holes. The broach produces about 100 per hour.

Fig. 52 illustrates the broaching out of poppet heads used on textile machines. They are machined two at a time, two being shown in the machine and two on the pan, all being indicated by *A*. The cast-iron pieces are 3 in. thick and have a slot cut in them 1 3/4 in. wide and 2 1/4 in. deep. The pieces to be broached are set on the platform *B* and the cross-piece *C* put in place. The bar *D* is then screwed down on it by means of the small handwheel on screw *E*. The rate of production on these is about 60 per hour, or one a minute.

THE LARGEST BROACHING MACHINE EVER BUILT (1917)

It is seldom that one can definitely say when a certain machine is the largest ever made of its kind, but this can be safely said of the broaching machine shown in Fig. 53. It is shown here because it is not only the largest machine of its kind ever made, but it is also illustrative of the latest practice in the use of multiple broaches on a single piece of work. This machine was made by the J. N. Lapointe Co., New London, Conn. and it weighs 14,700 lb. and broaches 12 rectangular grooves at once. These grooves are 3/8 in. wide and 14 in. long. The machine was originally designed for the use of a large electric company and the work shown being broached is a motor frame. These frames are 22 in. inside diameter and the holding fixture or work bushing on the head of the machine, alone weighs 700 lb. Every part of the machine is made especially heavy to support the great load. Triple-operating handles are provided on each side to enable the operator to control from the most convenient position. A telescoping housing protects the screw where it projects at the rear, keeping it safe from injury and also safeguarding the workmen. The drawhead nut is made of Lumen bronze, is 30 in. long and is threaded to fit the 5-in. operating screw. The drive is direct through a silent chain from a 15-hp. motor. The return of the drawhead is made at the rate of twice the working stroke, 5 min. being the total time taken to broach the 12 grooves. The outer ends of the cutter bars are connected by means of radial springs which draw then to a common center. The rear ends of the bars are cut away on the inside so that when the drawhead is out, ready for the return stroke, the cutters are drawn inward clear of the work, which can then be easily slipped on or off the work holder on the faceplate. The machine has a stroke of 6 ft.; is 18 ft. 10 1/4 in. long; 56 1/2 in. wide and 55 1/2 in. high, an extra length of 82 in. being required for the stroke of the broach forward. The screw is 5 in. in diameter with 1/2 thread to the inch. The 15-hp. motor runs at 600 r.p.m.

FIG. 53.—Broaching twelve slots at once.

A VERY UNUSUAL JOB

The machine and work shown in Figs. 54 and 55 were first shown and described in the *American Machinist* of July 9, 1908, yet it is still an example of unusual work. A Lapointe machine is used. The work itself is a steel

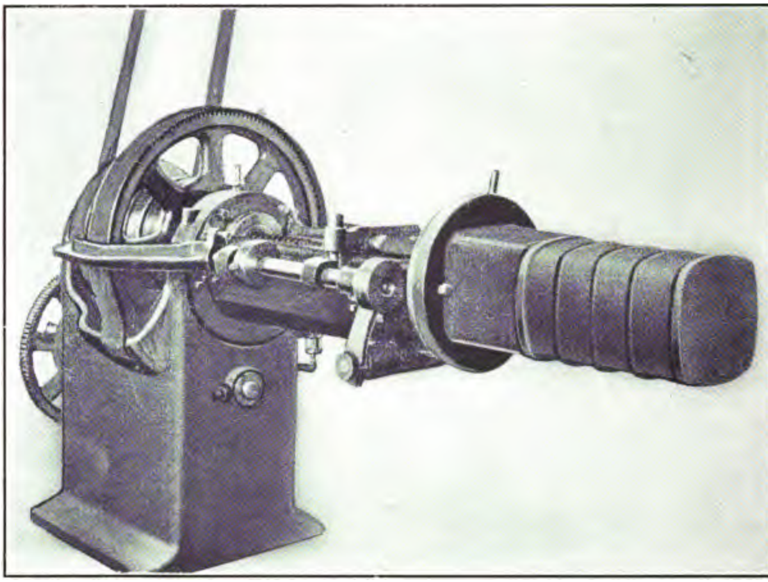


FIG. 54.—An unusual broaching job.

casting having a box-like opening as shown. This is all broached except the grooves in the center of each side, and it tapers outward ½ in. from each

FIG. 55.—The broach used and the work.

corner. The cut must start from the bottom in a shallow recess or chamber, 3 in. long. The hole is approximately 8 in. square and the cut is 14 in. long. The broach is in four parts, each sliding on one side of the mandrel, which is tapered to correspond with the hole to be cut, and the four broaches are pulled together by the rods shown. These rods are arranged so as to allow the separation necessary as they are pulled up the incline. To put the work on, the broaches are moved to the extreme outer end of the mandrel, and project halfway over it. Then the work is slipped on over them. Starting the machine pulls the broaches up the inclines and starts them to work. The chips taken out are shown on top of the holder and in the broach. The amount of stock removed is about 1/16 in. thick by 8 in. across or around the corner, and 14 in. long. It is estimated by the builders of the machine that these broaches require a pull of from 75 to 100 tons.

EXTERNAL BROACHING

External broaching is continually growing in favor for work of various kinds which have heretofore been done in other ways. Only a few examples will be shown to illustrate the main principles involved. Fig. 56 shows a method of squaring the ends of rods, some of the finished ends being shown on the rods lying against the machine. The work is done in two operations, that is with two pulls of the broaches. The arrangement is a jig made in the form of a box in which slide two broaches with teeth on the inner side to broach the two opposite faces of the square to be made on the rod. After the broaches have finished the two opposite faces on the rod, the rod is reset for the final cut, that is, the dog in which the rod is fastened is indexed 1/4 turn, bringing the work in position for the second operation to broach the other two opposite faces on the square.

BROACHING FLATS ON BEARINGS

Another example of external broaching is shown in Fig. 57. These bearings are broached to fit the fork shown at *B*, the piece being slipped in as shown at *A*. Two pieces *F* are broached at a time, being set into the holder *C* and the broaches *D* and *E* drawn through the outer guides, broaching the flats as indicated.

A job that is commonly milled is shown being broached in Fig. 58. The piece broached is shown in Fig. 59, the broached surfaces being outlined in heavy black lines. The accuracy and finish are very close, and from 80 to 100 pieces are finished per hour, two pieces being broached at one time by the two external broaches shown. The method of holding is plainly indicated on the machine.

BROACHING THE OUTSIDE OF A CORE FOR AN AUTOMOBILE-WHEEL HUB

An interesting job is shown in Fig. 60. This consists in broaching the outside of a core for an automobile-wheel hub, a blank and a finished

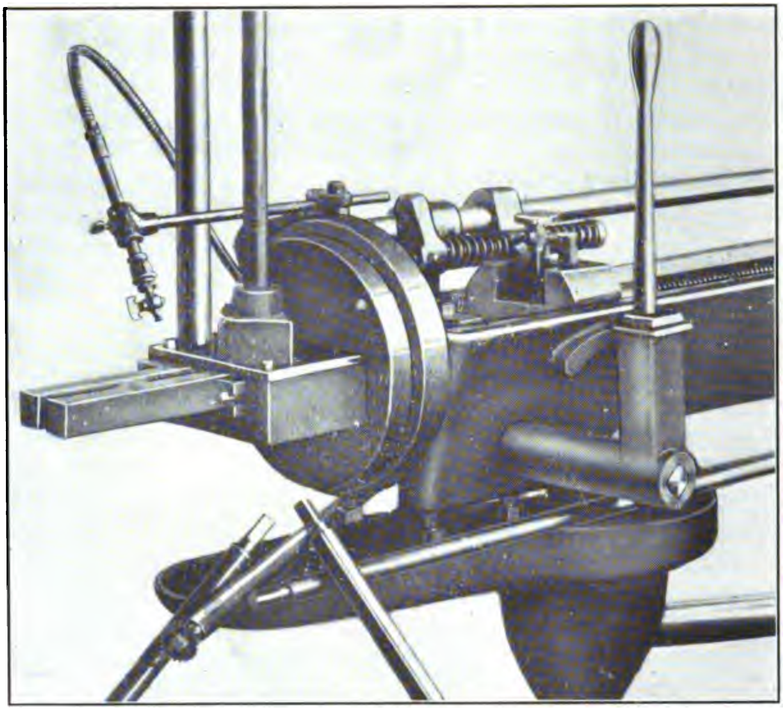


FIG. 56.—Squaring the ends of rods.

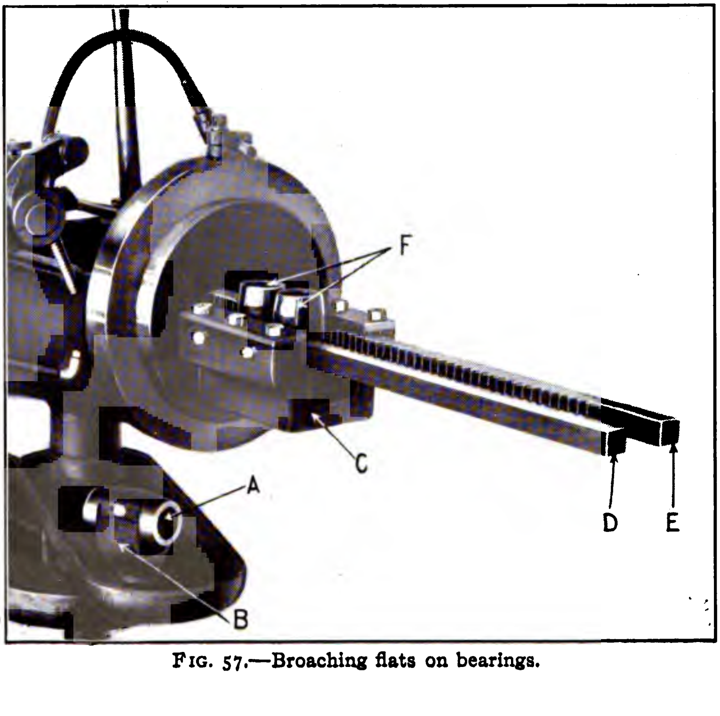


FIG. 57.—Broaching flats on bearings.

core being shown in Fig. 61. These cores are about 2¼ in. in diameter and 3 in. long. The core is attached to a mandrel and is pulled through a die broach which makes 36 grooves, 3/32 in. wide by 3/64 in. deep, at the rate of 45 pieces per hour. This is a record that no milling or hobbing machine could approach.

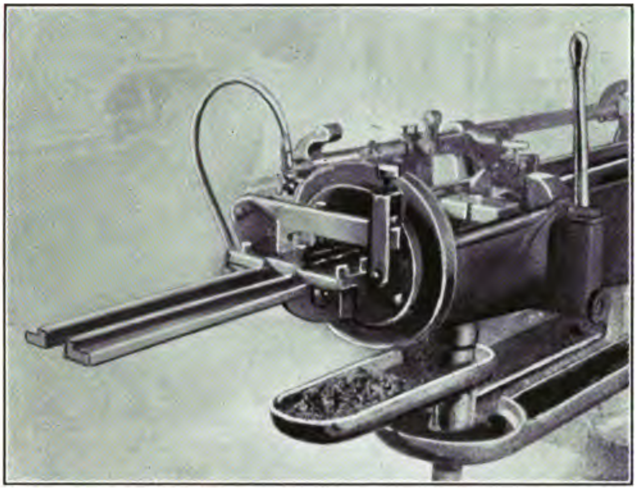


FIG. 58.—Broaching a piece that is usually milled.

TWO VERTICAL PULL-BROACHING MACHINES

Vertical pull-broaching machines are only built special or are used for some special job. Under certain conditions they have some advantage over the horizontal types, though as a rule vertical broaching is push broaching. The vertical machines here shown are the only ones of which we have any record as being used for pull-broaching work.

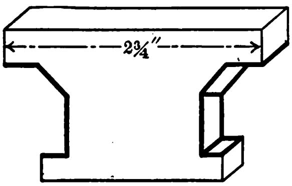


FIG. 59.—The piece that is broached.

Fig. 62 shows a machine used by the Davis Boring Tool Co., St. Louis, Mo., to broach out the rectangular tool slots in their boring bars. Another feature is that diagonal tooth broaches and differential tooth spacing are used. These broaches will be described in detail in another chapter. The machine shown is geared 42 to 1 and the travel of the screw is from 10 to 48 in. per min. on the pull, with an accelerated return. The total possible screw travel is 38 in. The side bar and uprights are $3\frac{1}{2}$ in. by 4 ft. and the screw is $3\frac{1}{2}$ in. in diameter. The bars broached on this machine are of 60-point carbon steel and range in size from $1\frac{1}{4}$ to $6\frac{1}{2}$ in. in diameter, some of them weighing in the neighborhood of 300 lb. The slots for

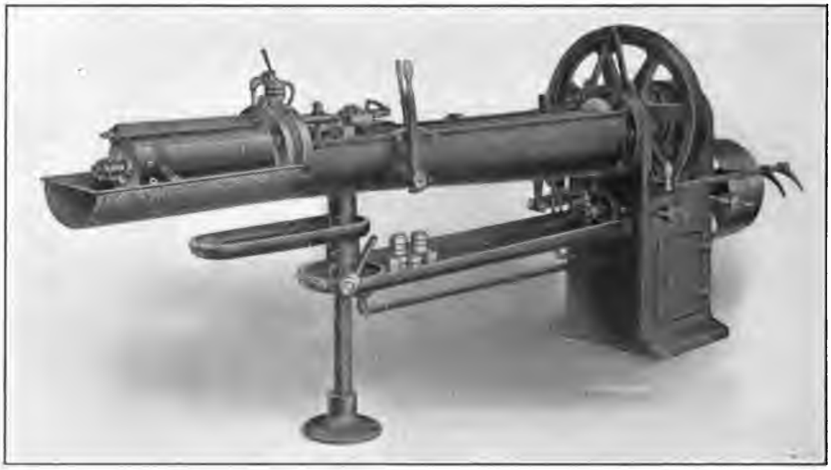


FIG. 60.—Broaching a core for an automobile hub.

the cutters are first milled in the bars in a Pratt & Whitney double-spindle automatic spline milling machine. The slots are milled to within 0.006 to 0.01 in. of finished width and 0.005 to 0.01 in. of the right length. They are then broached to rectangular form. Owing to the toughness of

FIG. 61.—A broached and a blank core.

the metal the strain is too severe for a single broach to finish at one pass, so three are used, two for the ends and one for the sides, the ends being broached first. The first broach is rounded on the end to fit the milled hole and gradually becomes rectangular in shape so as to square the ends of the slot. This broach leaves about 0.01 in. on each end for the second broach to cut. The second broach finishes the ends and is a very important tool, as these ends must be absolutely square with the center line of the bar. The third broach cuts on the sides only and to within about 0.001 in. of the ends.

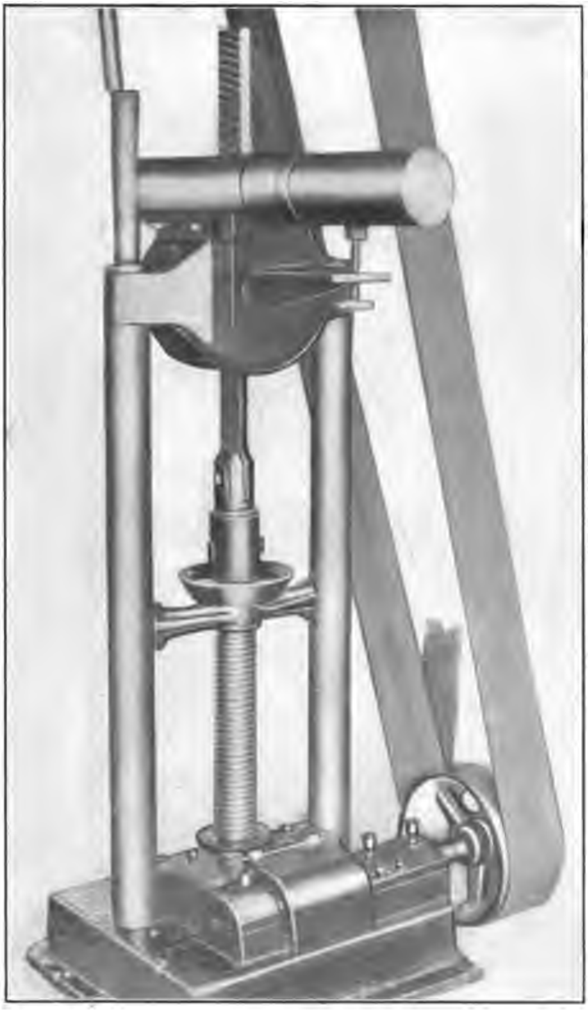


FIG. 62.—Vertical machine used for heavy rectangular broaching.

The machine shown in Fig. 63 is a keyseating machine used in the shops of International Harvester Co., Milwaukee, Wis., to keyseat small gas-engine flywheels. The keyways are finished at one pass of the broach. The flywheels are placed on the top of the table down over the broach which is then pulled down through the work. The drawscrew runs continuously and the drawhead is pulled down over it until the drawnut mechanism hits a bevel stop at the bottom, which opens the split nut in the drawhead, and allows it to return to the top as it is counterbalanced by weights which act

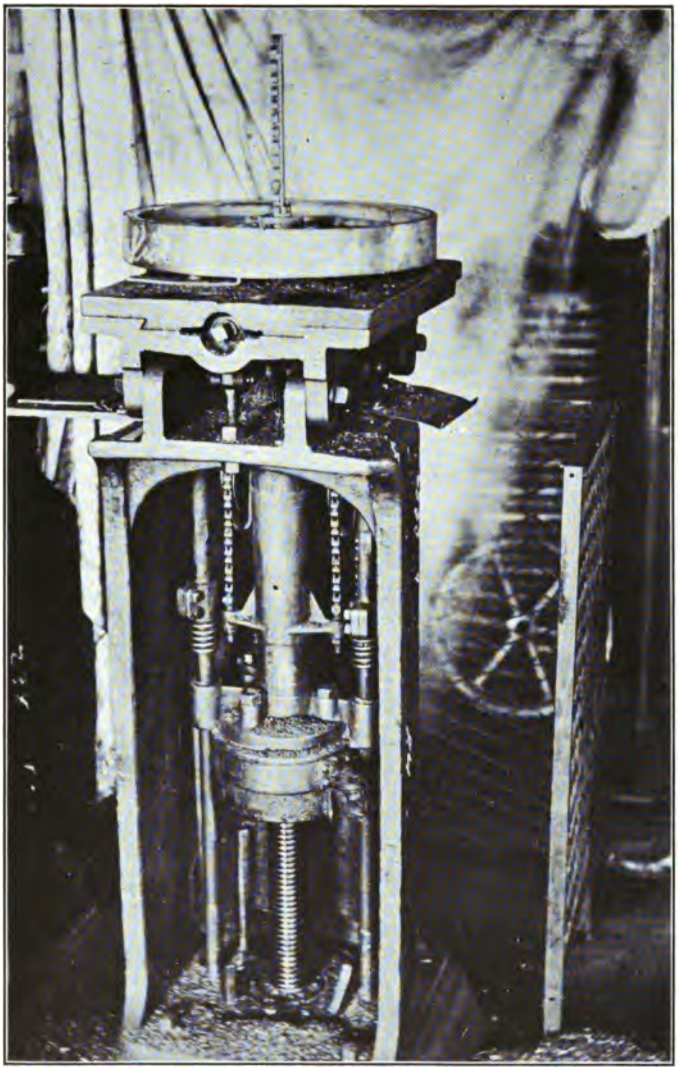


FIG. 63.—Vertical pull machine for keyseating.

on the two bicycle chains shown. After the drawhead and broach have returned to the upper position and the work is in place, the operator closes the split nut and the broach is drawn down again.

LUBRICANT USED FOR STEEL WORK

The J. N. Lapointe Co., New London, Conn., recommends the use of the following mixture, when broaching steel:

Soda ash	2½ lb.
Mineral lard oil	3 gal.
Water	50 gal.

Mix the soda ash and the oil, with 10 gal. of water, and then add the other 40 gal.

TIME REQUIRED TO BROACH VARIOUS KINDS OF WORK

In Fig. 64 is shown a collection of broached samples, which are numbered, and following is a description of each numbered piece together with the time required for the work. The illustration is taken from the catalog of the Lapointe Machine Tool Co., Hudson, Mass., and is representative of the average shop practice:

No. 1. Hexagon Hole with One Round Side.—Distance across flats 1⅛ in., length 1½ in., material steel. No. 2 machine. Production 45 pieces per hour.

No. 2. Four Splines.—Hole 1⅞ in. diameter, splines ¾ by 3/16 in., 2¼ in. long, material steel. No. 3 machine. Production 20 pieces per hour.

No. 3. Square Hole.—Distance across flats 1 in., 1½ in. long, material steel. No. 2 machine. Production 40 pieces per hour.

No. 4. Four Spiral Keys.—Diameter of hole 1 in., keys ½ by ⅛ in., 2 in. long, material steel. No. 3 machine. Production 15 pieces per hour.

No. 5. Clutch Used on Mining Machinery.—Diameter of hole 2⅞ in. Double depth of slots 3¾ in., length 2 in., material steel. No. 3 machine. Production 20 pieces per hour.

No. 6. Solid Key.—Taken from 1¼-in. round hole, leaving solid key ½ by ⅛ in., length 2½ in., material steel. No. 3 machine. Production 15 pieces per hour.

No. 7. Six Radial Splines.—Diameter of hole 2⅛ in., splines ⅝ by ⅛ in., 2⅛ in. long, material steel. No. 3 machine. Production 20 pieces per hour.

No. 8. Housing for Bronze Bearings.—Openings 4½ by 1½ in., 2 in. through, material C. I. No. 3 machine. Production from rough casting 20 pieces per hour.

No. 9. Square Hole.—Distance across flats 2 in., length 3⅛ in., material steel. No. 3 machine. Production from a drilled hole, 15 pieces per hour.

No. 10. Square Hole.—Distance across flats 3 in., length 4 in., material steel. No. 4 machine. Production from drilled hole, 15 pieces per hour.

No. 11. Three Dovetail Splines.—Diameter of hole 1⅝ in., splines 1 by 3/16 in., 2 in. long, material brass. No. 3 machine. Production 45 pieces per hour.

No. 12. Eight Dovetail Splines.—Diameter of hole 3⅝ in., splines ¾ by 3/16 in., 3 in. long, material steel. No. 4 machine. Production 15 pieces per hour.

No. 13. Square Hole.—1⅜ in. across flats. 5 in. long, material steel. No. 3 machine. Production from drilled hole, 15 pieces per hour.

No. 14. Universal Joint Part.—Hole 2 7/16 in. across flats, ¾ in. through, material C. I. No. 3 machine. Production 30 pieces per hour.

No. 15. Babbitt Bearing.—Diameter 2 in., length 2¼ in. Broached to exact size, compressed and burnished. No. 3 machine. Production 60 pieces per hour.

No. 16. Round Hole.—3 in. diameter, 4⅜ in. long, material C. I. No. 3 machine. Production from cored hole 30 pieces per hour.

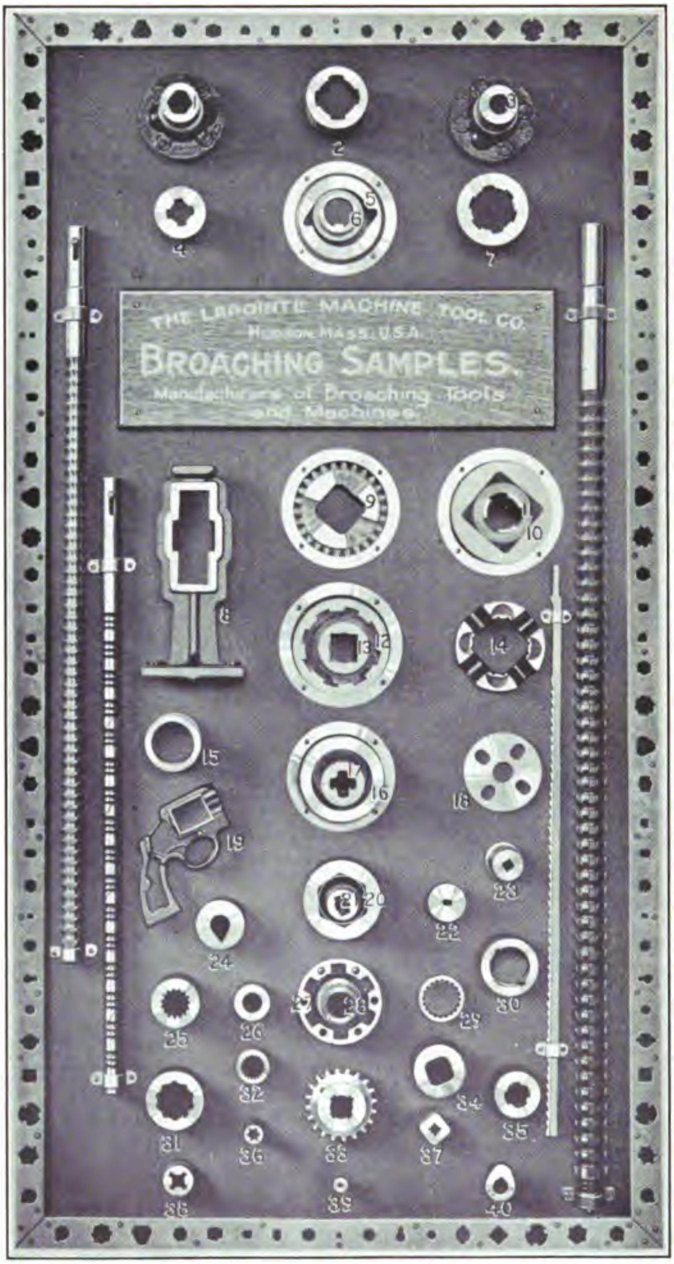


FIG. 64.—Typical samples of broached work.

No. 17. Cruciform Used in Mining Machinery.—Splines $\frac{1}{2}$ by $\frac{3}{8}$ in., 7 in. long, material steel. No. 3 machine. Production from $\frac{7}{8}$-in. round hole, 7 pieces per hour.

No. 18. Oval-shaped Holes.—$\frac{13}{16}$ by $\frac{5}{8}$ in., $\frac{1}{4}$ in. through, material steel. No. 2 machine. Production approximately 600 holes per hour.

No. 19. Revolver Frame.—Size of hole for chamber $1\frac{13}{16}$ by $1\frac{1}{2}$ in., $\frac{3}{4}$ in. through, material steel. No. 2 machine. Production from rough forging 20 pieces per hour.

No. 20. Hexagon Hole.—Distance across flats $2\frac{3}{8}$ in., $2\frac{1}{8}$ in. long, material steel. No. 3 machine. Production from drilled hole 40 pieces per hour.

No. 21. Two-spline Hole.—$1\frac{1}{8}$ by $\frac{9}{16}$ in., $3\frac{1}{2}$ in. long, material steel. No. 2 machine. Production from $\frac{3}{4}$-in. drilled hole, 10 pieces per hour.

No. 22. Hole.—$\frac{1}{2}$ by $\frac{5}{16}$ in., $\frac{1}{2}$ in. long, material steel. No. 1 machine. Production from drilled hole 25 pieces per hour.

No. 23. Square Hole.—$\frac{1}{2}$ in. across flats, 2 in. long, material steel. No. 1 machine. Production from drilled hole 20 pieces per hour.

No. 24. Pear-shaped Hole.—Diameter of round broach 1 in., $1\frac{3}{8}$ in. long, material steel. No. 2 machine. Production 20 pieces per hour.

No. 25. Internal Gear.—Hole $1\frac{1}{4}$ in., $1\frac{7}{8}$ in. long, 15 teeth, material steel. No. 3 machine. Production from drilled hole 40 pieces per hour.

No. 26. Internal Ratchet 140 Teeth.—Diameter of hole 1 in., length $1\frac{1}{8}$ in., material steel. No. 2 machine. Production 45 pieces per hour.

No. 27. Six Splines.—Diameter of hole $2\frac{3}{4}$ in., splines $\frac{3}{4}$ by $\frac{1}{2}$ in., 1 in. long, material drop-forged steel. No. 4 machine. Production 35 pieces per hour.

No. 28. Bronze Bushing.—Hole $\frac{15}{16}$ in. in diameter, $1\frac{7}{8}$ in. long. No. 3 machine. Broached to exact size, compressed and burnished. Production from cored hole 100 pieces per hour.

No. 29. Magneto Coupling.—Hole $1\frac{3}{4}$ in. in diameter, $\frac{1}{2}$ in. long, 20 teeth, material steel. No. 3 machine. Production from drilled hole 90 pieces per hour.

No. 30. Two Spiral Keyways.—Diameter of hole 2 in., keyways $\frac{1}{4}$ by $\frac{1}{8}$ in., $1\frac{7}{8}$ in. long, material steel. No. 3 machine. Production 40 pieces per hour.

No. 31. Ten Splines.—Diameter of hole $1\frac{3}{4}$ in., splines $\frac{1}{4}$ by $\frac{1}{8}$ in., $1\frac{1}{4}$ in. long, material steel. No. 3 machine. Production 45 pieces per hour.

No. 32. Tool-steel Die for Pressing Tin Top on Bottles.—Diameter of hole $1\frac{1}{16}$ in., $\frac{7}{8}$ in. long, 21 teeth. No. 2 machine. Production from drilled hole 60 pieces per hour.

No. 33. Four Spline.—Diameter of hole $1\frac{1}{8}$ in., splines $\frac{5}{16}$ by $\frac{1}{8}$ in., $1\frac{1}{4}$ in. long, material steel. No. 2 machine. Production 45 pieces per hour.

No. 34. Taper Square Hole.—Distance across flats, small end, $1\frac{1}{4}$ in., large end $1\frac{1}{2}$ in., 2 in. long, material steel. No. 2 machine. Production 12 pieces per hour.

No. 35. Four Solid Keys.—Diameter of hole $1\frac{1}{16}$ in., keys $\frac{5}{16}$ by $\frac{1}{8}$ in., $1\frac{5}{8}$ in. long, material steel. No. 3 machine. Production 20 pieces per hour.

No. 36. Bushing for Trolley Wheel.—Diameter of hole $\frac{1}{2}$ in., six spiral keyways $\frac{1}{8}$ by $\frac{1}{16}$ in., $1\frac{1}{2}$ in. long, material bronze. No. 2 machine. Production 100 pieces per hour.

No. 37. Four Splines in Taper Hole.—Hole $\frac{1}{2}$ in. in diameter at small end, $\frac{5}{8}$ in. in diameter at large end, splines $\frac{1}{8}$ by $\frac{1}{16}$ in., $\frac{1}{2}$ in. long. Splines parallel with taper, material steel. No. 1 machine. Production 25 pieces per hour.

No. 38. Four Splines.—Diameter of hole $\frac{5}{8}$ in., splines $\frac{1}{4}$ by $\frac{1}{4}$ in., $\frac{3}{4}$ in. long, material steel. No. 1 machine. Production 15 pieces per hour.

No. 39. Single Keyway.—Diameter of hole $\frac{1}{4}$ in., keyway $\frac{5}{64}$ by $\frac{1}{16}$ in., $\frac{3}{8}$ in. long, material brass. No. 1 machine. Production approximately 250 pieces per hour.

No. 40. Single Keyway.—Diameter of hole $\frac{3}{4}$ in., keyway $\frac{3}{16}$ by $\frac{3}{32}$ in., 1 in. long, material steel. No. 1 machine. Production 160 pieces per hour.

5

CHAPTER IV

EXAMPLES OF PUSH-BROACHING WORK AND PRACTICE

Many manufacturers consider that for certain kinds of work, the push-broaching method is superior to the pull method. The broaches themselves have to be made shorter and heavier in order to prevent deflection, and usually a number, sometimes as high as 20 or more, are required to finish a hole. This is not so remarkable when one stops to consider the rapidity with which a push broach may be handled. However, a careful comparison of the various jobs described will do more to satisfy a man as to whether this method is adapted to his particular class of work than would any lengthy argument.

BROACHING UNIVERSAL JOINTS

Some interesting push-broaching work on universal joints is done in the shop of the Spicer Mfg. Co., Plainfield, N. J., and the following data and accompanying pictures were obtained there. Two kinds of presses are used—hydraulic and crank. The latter, however, is used principally for emergencies. One of the big 20-ton Watson-Stillman presses is shown in Fig. 65. In using this machine, a set of broaches is laid in order at one side of the work. The work is put into the holder and then the man at the back of the machine sets the first broach in place. The press operator pulls the valve lever and the broach is driven through, dropping down underneath. The helper inserts the next broach the instant the ram rises, wipes the chips off the previous one and lays it on the other side of the machine.

In this way, a set is transferred from one side of the machine to the other, for each complete hole cut. The ram descends at a steady, uniform rate, but the return is quick, which is one great advantage of this class of machine. The average time for the descent and return of the ram is from 10 to 15 sec., depending on the size of broach being used.

The method of holding the work and placing the broaches is more clearly shown in Fig. 66. Boards are provided to lay the broaches on to prevent injury to the teeth and the marring of the machine. The method of applying the lubricant in two good-sized streams close to the work is also shown.

Broaching with a Crank Press

A large crank press used for broaching is shown in Fig. 67. This is not so satisfactory a method of doing the work as by the use of a hydraulic press, one reason being that the stroke and return of the ram are made at the same rate. Another reason is that the speed of the stroke varies according to the position of the crank, therefore the speed of the press must be set so that the fastest speed of the ram, at any given point, does not exceed

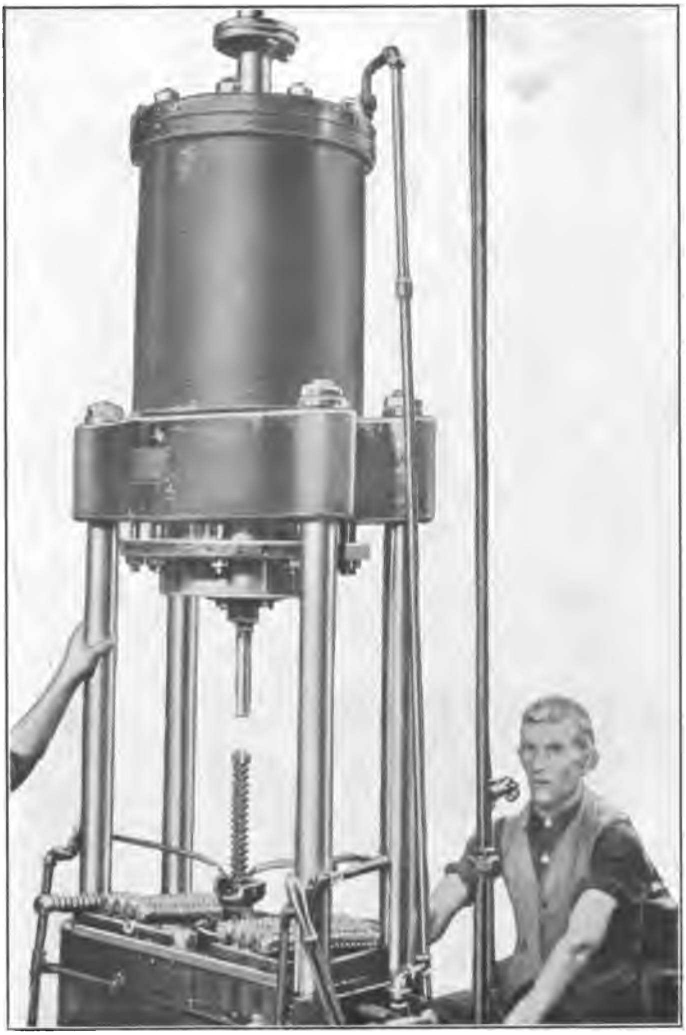


FIG. 65.—Broaching on a 20-ton Watson-Stillman press.

the safe cutting speed for the broaches used. This makes the output of a machine of this kind considerably below that of the hydraulic type.

For work of this kind, lard oil, as well as a number of other kinds, has proved useless, as the metal would tear. After considerable experimenting, a heavy oil, known as Vacuum Bolt Oil, selling around 50c. per gal., is being used with satisfactory results. Apparently the pressure between the tools and the work precludes the use of any of the lighter-bodied oils.

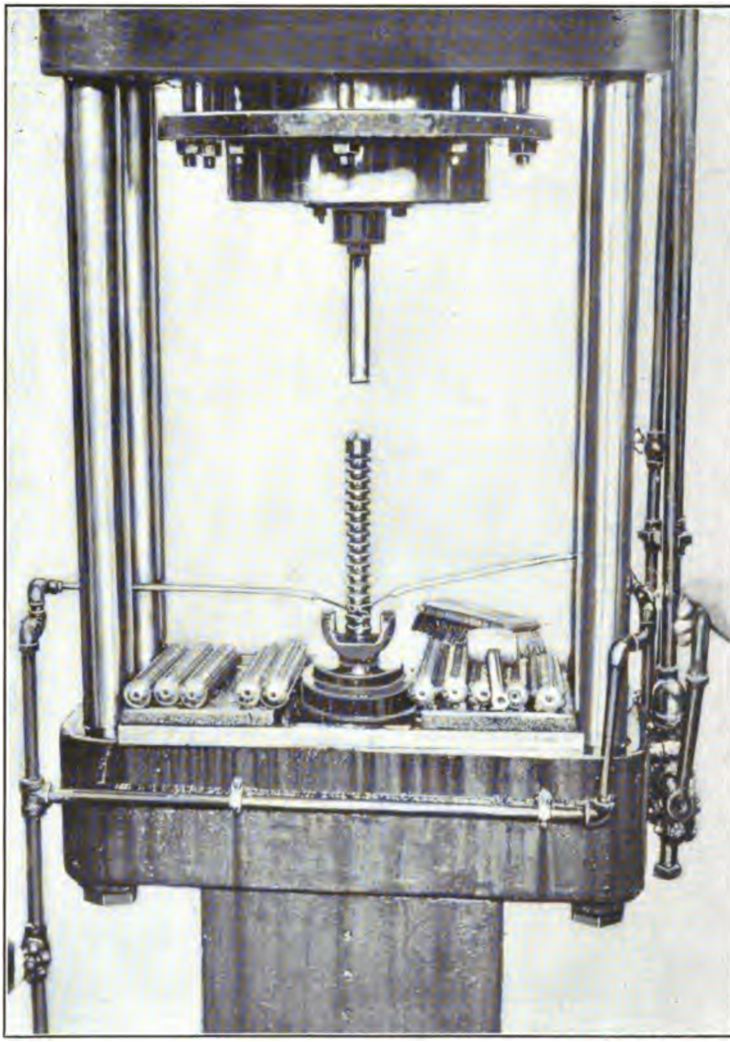


FIG. 66.—Closer view of broaches and work

BROACHING CONNECTING-ROD ENDS

Several examples of connecting-rod work with pull broaches were shown in the previous chapter. Here is shown the push-broaching work done on connecting-rod ends in the Detroit shop of the Continental Motor Co. Fig. 68 shows the broaching of the small end. The final diameter of the small end is 0.877 in., the last tooth of the broach leaving it 0.876 in., an allowance of a thousandth for final burnishing. These broaches have seven lands, although the total length is but 9 in. These lands vary by steps of 0.0005 in. This is a hydro-pneumatic press built by the Chambersburg Engineering Co.

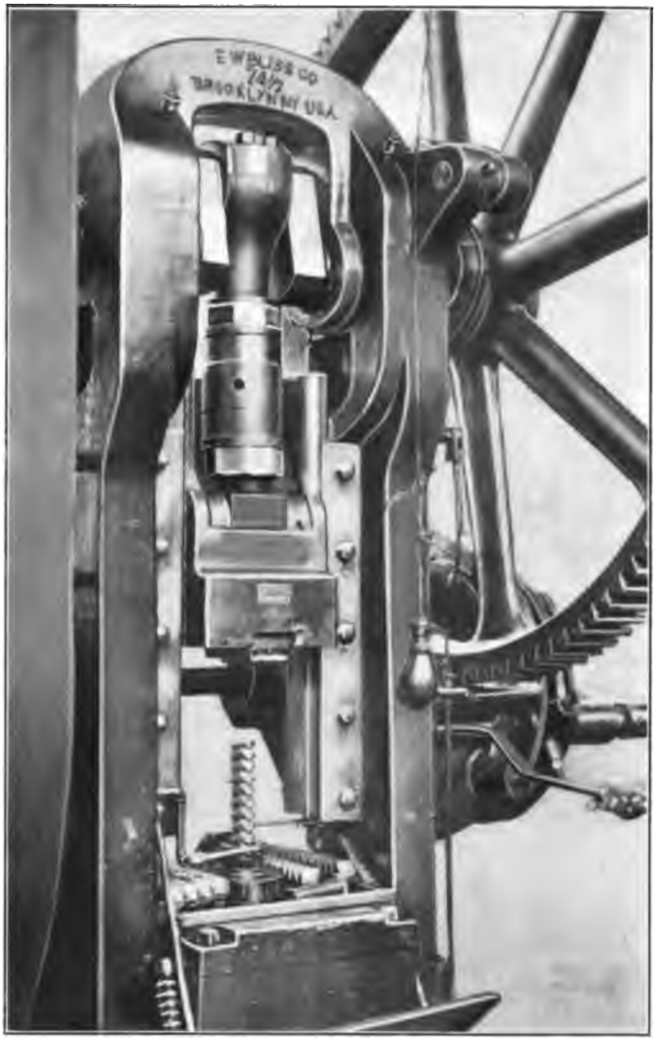


FIG. 67.—Broaching on a crank press.

The main air plunger of this press is 13½ in. in diameter with 80 lb. air pressure. The intensifier piston is 2 9/16 in. and the main ram of the press is 4¼ in. in diameter. The intensifier gives a pressure of 2115 lb. per sq. in. or a total of 15-ton pressure on the ram. For this work, however, the pressure runs from 500 to 600 lb.

Fig. 69 shows the broaching of the large ends of the connecting-rods on a Lucas power press. The finished size is 1.995 in., the last thousandth of an inch being secured by a burnisher, which follows the broaching. The broach

FIG. 68.—Broaching small end of connecting rod.

is 13½ in. long but carries only seven cutting edges, or lands, as can be seen. Each land removes 0.001 in., and, with the remaining thousandth to be taken care of by the burnisher, this makes 0.008 in. total allowance for finishing.

The pressure varies from 2000 to 2500 lb., while the burnishing requires from 3500 to 4000 lb. total pressure. These rods can be handled very rapidly, 1200 being broached in a day.

FIG. 69.—Broaching the large end of the rod.

Another connecting-rod job is shown in Fig. 70. This picture was taken in the shop of the Packard Motor Car Co., Detroit, Mich. The press used is of the vertical-screw spindle type. No holding jig of any kind is used, except a cast-iron block with a hole in the center as shown.

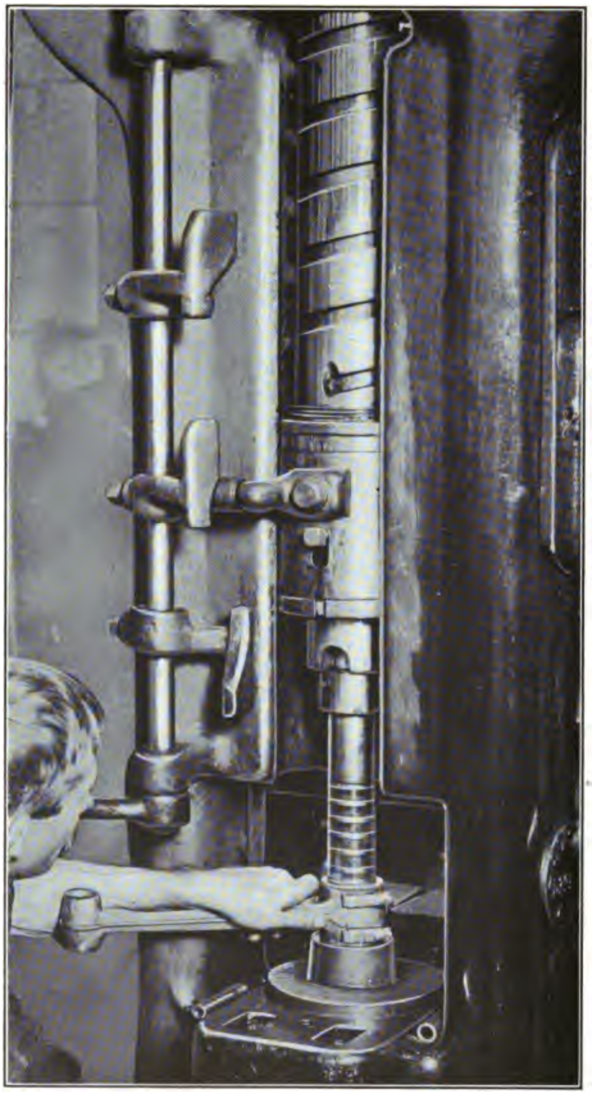


FIG. 70.—Connecting-rod work in the Packard factory.

BROACHING PARTS OF LIFTING JACKS

The Joyce-Cridland Co., of Dayton, Ohio, machine a number of the parts used in their lifting jacks by means of broaching operations performed in an 80-ton hydraulic press of their own manufacture.

CHARACTER OF THE WORK

Some of the jack parts handled in this manner are illustrated in Fig. 71, which is a group representing several sizes and forms of broaches, a number of

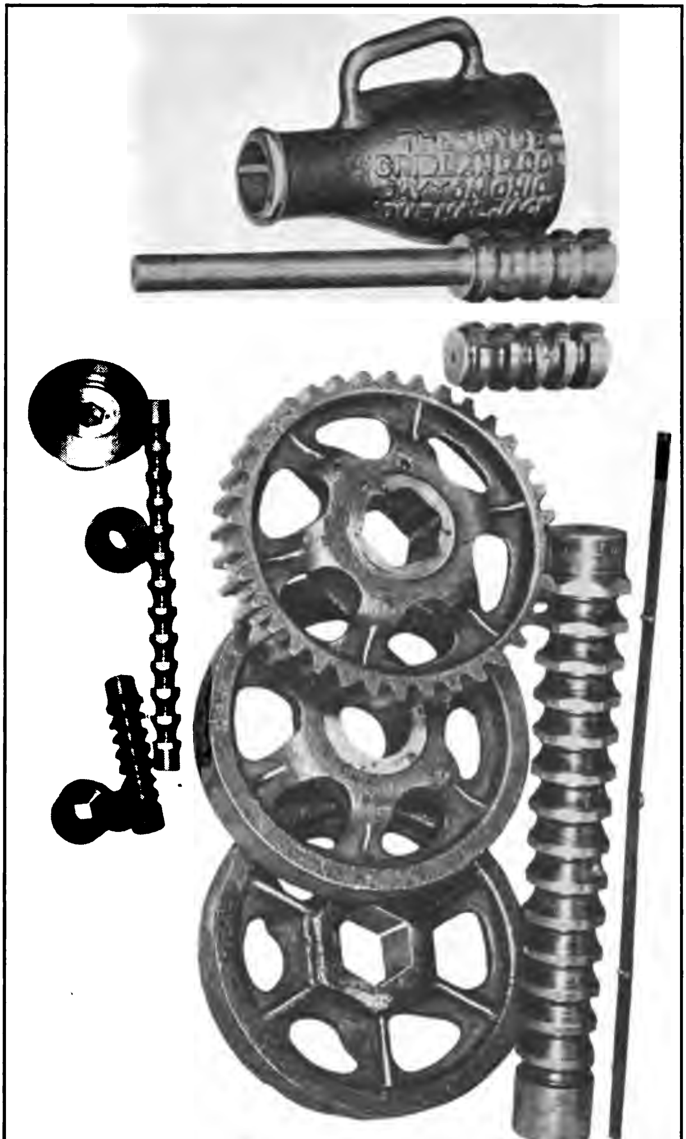


FIG. 71.—Parts of lifting jacks and broaches used.

gear wheels for automatic geared-lever jacks; a screw-journal jack frame, and several parts for jacks of other types.

The hexagonal holes in the gears are broached before the teeth are cut, as indicated by the engraving, which shows a blank with the hole chucked through the hub, and a pair of such gears with broached bores, one before cutting the teeth, the other after. These gears are steel castings and they are made in various sizes for the different jacks. The ones illustrated are 12 in. in diameter.

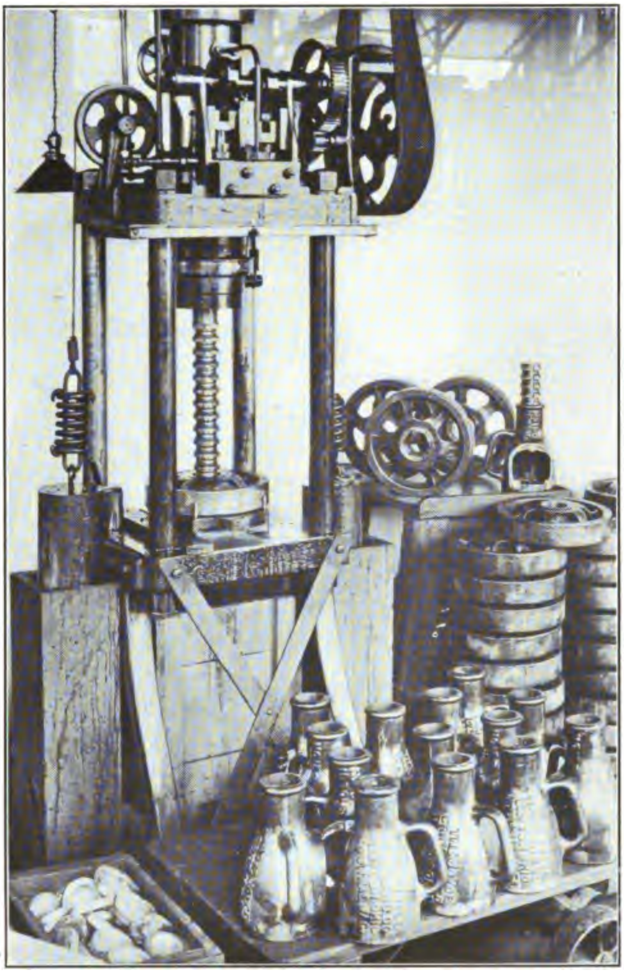


FIG. 72.—Broaching hexagon hole through gear-blank hub.

BROACHING THE HEXAGONAL HOLE

The hexagonal hole in the gear hub is $2\frac{5}{8}$ in. across and the distance through the hub is 3 in. The work is performed in the hydraulic press shown in Fig. 72, with the gear blank placed in a fixture, through which the broach can pass, on its way down through the work.

The operation is completed with one broach, leaving an accurate, smooth hole which in the assembling of the jack, receives the six-sided hub of the pinion that operates the jack bar or ram.

Forming a Solid Key in a Broached Hole

In the foreground of Fig. 71 there are a number of bases or frames for screw-operated journal jacks, and one of these bases will be noticed to the right of the group of work and tools in Fig. 72. A cylindrical ram is used in this jack, the operating screw passing up inside the lower end of the ram, and the latter having a keyway fitting a solid key in the neck of the base that prevents the ram from rotating with the motion of the screw. This key is plainly visible in the cylindrical opening at the top of the jack base in Fig. 71. It is about 3/8 in. wide in the size of jack illustrated, and is formed at the same time as the hole itself is finished. Two broaches are used for this operation, both of which are shown at the side of the jack base. The one at the left, that is, the solid broach, performs the roughing of the bearing, while the other, which is bored out to receive a guide arbor, is used for finishing.

Order of Operations

The broaching is accomplished under the same press. The first, or roughing broach is pushed through the cored hole, leaving a few thousandths inch of metal all the way round the hole and key for finishing. The jack base then goes to the drill press, where a hole is put through the bottom for the lower end of the jack screw and a concave seat machined for the reception of the lower bearing plate of a roller bearing which takes the load on the screw.

The Finish-broaching Process

After the work in the drill press is completed, the jack bases are taken back to the hydraulic press where, with the second broach, the bearing surface for the ram and the controlling key are finished.

In this operation, which is illustrated in Fig. 73, the broach is guided on a spindle or arbor that passes down through the hole at the bottom of the jack base and assures the broach taking a true course down through the neck of the casting, leaving a smooth cylindrical guide for the ram, and a straight, correctly sized key for the splined guide in the side of the ram.

Broaching Out a Bevel-gear Hub

A bevel gear is shown in the background of Fig. 71, with a long broach in front with which a hexagonal hole is formed in the gear hub. This gear is used on the hexagonal shank of the elevating screw of the jack. Fig. 74

illustrates the work and broach more clearly and also shows the fixture in which the gear is held during the operation under the hydraulic press. The hexagonal hole is 1 in. across, and about 1⅛ in. deep. The material is a tough grade of steel. The gear blank is slipped into the fixture, and the broach is guided by the bore of the gear and the bushing secured in the top of the fixture. The cut is divided over 12 cutting edges and one broach does the work.

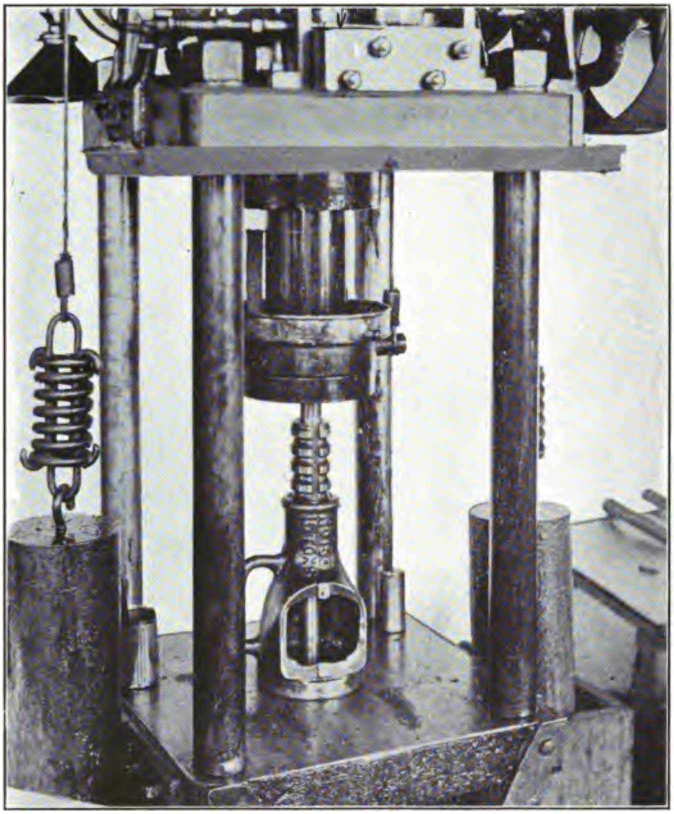


FIG. 73.—Broaching a guide bearing and solid key in jack base for ram.

BROACHING REVOLVER FRAMES

In the shop of the Iver Johnson's Arms and Cycle Works, Fitchburg, Mass., the cylinder space in revolver frames is broached out in a vertical machine, as shown in Fig. 75. The holding fixture is shown detached, and without a frame in place, in Fig. 76, the method of clamping being clearly shown. The broach is seen at *A*, and at *B* is a gage used to show whether the frame is being broached out so as to leave enough for finish on the other parts.

The method of using this gage is to place the frame over the block *C*, holding it closely in contact with the fingers, and then push in the sliding pins *D*. The pins have shoulders on them and are pushed in against the frame. If the shoulders are flush with the block, the work is correct, but if the shoulders go beyond or project from the block the work is incorrect.

WRENCH WORK

The following is an extract from an article by E. A. Suverkrop, which appeared in the *American Machinist*, March 27, 1913.

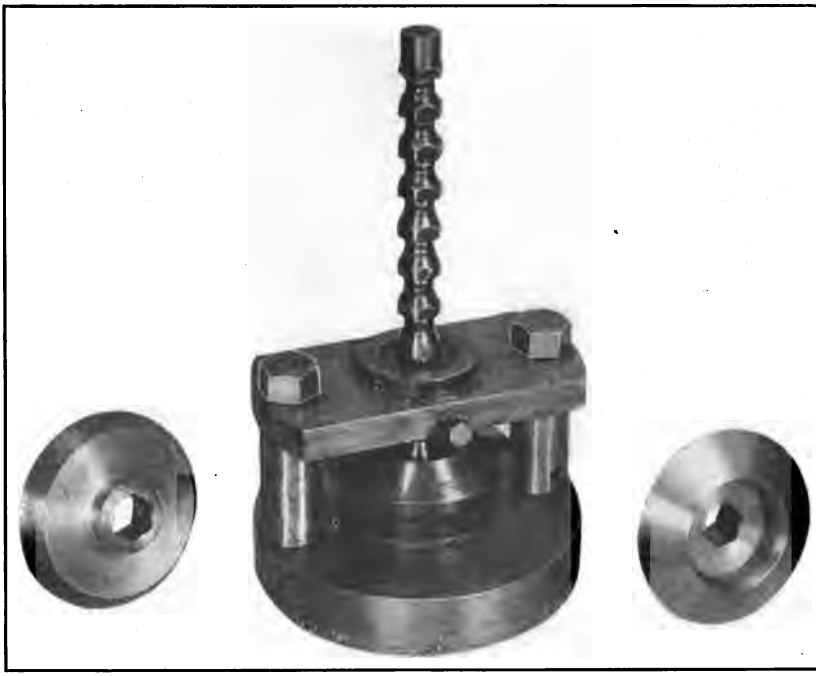


FIG. 74.—A sub-press fixture for broaching gears.

The drop-forged wrenches manufactured by the Billings & Spencer Co., Hartford, Conn., are so well known that the finished product needs no introduction. However, the methods used in their making will probably be of interest.

Apart from the operating screw and the small screw which holds this in place, the adjustable automobile wrench consists of but two parts. Both of these are drop forgings. The handle member has nothing of special interest about it, but the moving jaw is a particularly interesting piece of work. The rough forging with flash still attached is shown at *A*, Fig. 77, and at *B* is shown the forging after the flash has been removed by trimming dies. The interesting part of the manufacture begins at this stage.

A hole of the correct size is drilled through the cylindrical part of the forging *B*. After this the forging is squeezed in a header and assumes the shape shown at *C*. The hole drilled in *B* is of such size that when headed

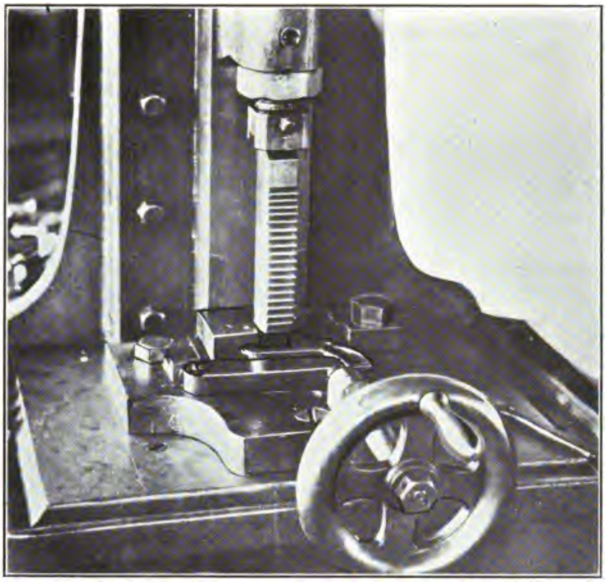


FIG. 75.—Broaching out revolver frames.

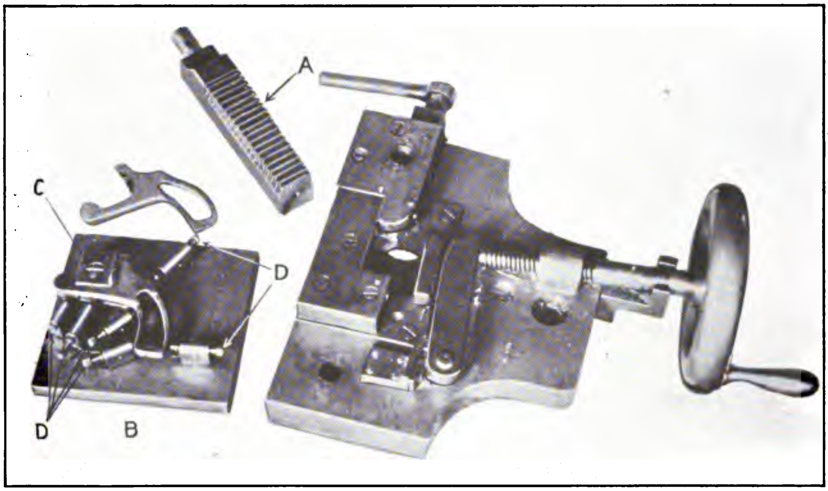


FIG. 76.—Fixtures and gage used.

up, the oblong hole will be small enough to clean up when the broaches *D*, *E*, *F* and *G* are pushed through it.

These broaches are of the push variety used in a Billings & Spencer broaching press. The upper end of each has a female center and the bottom end a

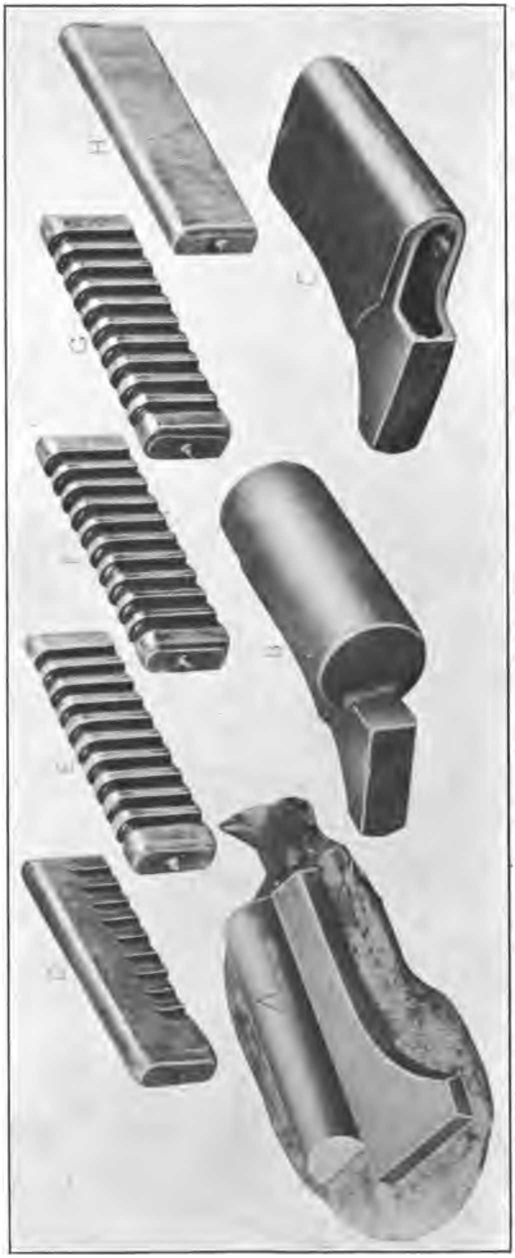


FIG. 77.—A set of follow broaches and the work.

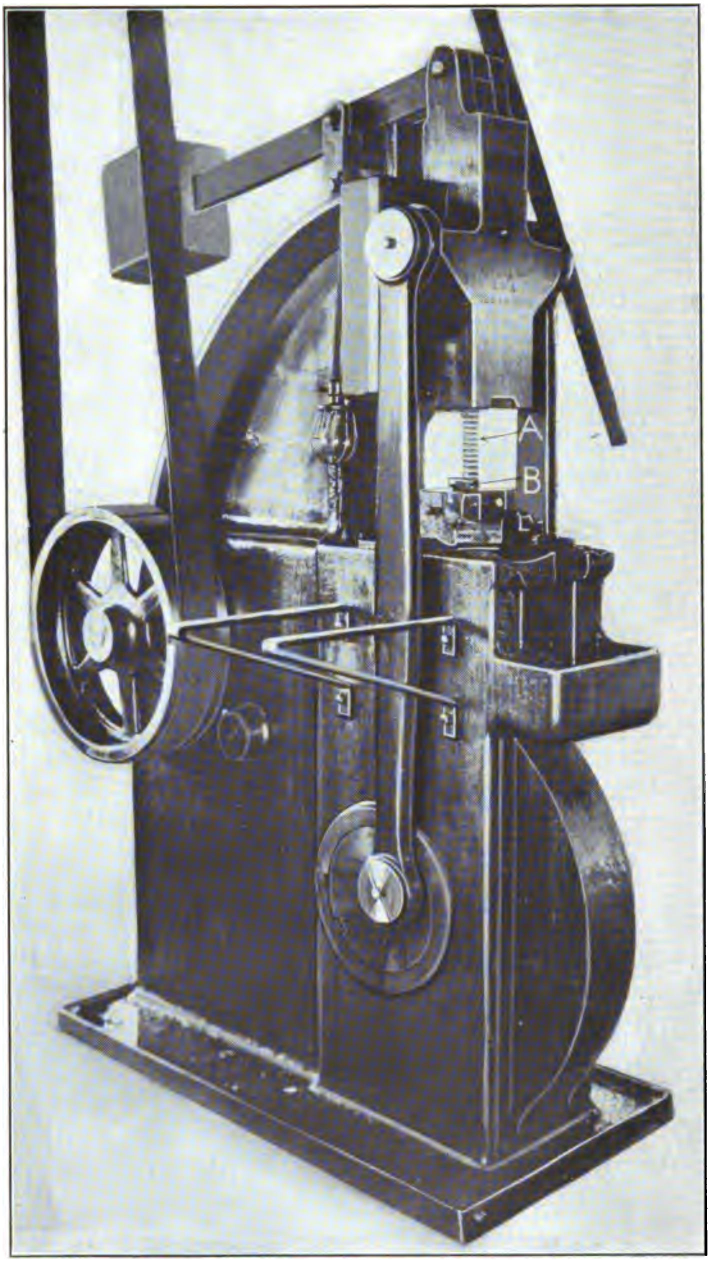


Fig. 78.—Billings & Spencer broaching press.

male center fitting it. These serve to locate the bottom end of each broach with relation to the one which has just preceded it. The sides of the upper ends of the broaches are chamfered off so that they are readily located in the chamfered female slot in the head of the broaching machine. The broaches are about 6 in. long and it takes about 3/4 min. to push the entire set through. The plain piece *H* merely acts as a pusher for the final broach.

Fig. 78 shows a Billings & Spencer broaching press pushing a broach *A* through one of the jaw forgings *B*. Fig. 79 shows the broaching of the hole *A* for the nut in the Billings & Spencer monkey wrench *B*. A thin sheet-steel inspection gage is shown at *C*. It is provided with a rectangular projection *D* to fit the hole broached by the broaches *E* and *F*.

A SUBPRESS FOR MOTOR CAMS

In Fig. 80 is shown a subpress designed to be used for broaching the keyways in cams for gasoline motors. The object sought and accomplished was to cut the keyway in correct relation to the rise of the cam. The base *D* is of gray iron, machined on the bottom, top of the two uprights and slotted for the locating plate *B*. There are two of these plates, one for the inlet and one for the exhaust cams, both being located on the bed of the subpress by screws and dowels. The plates were made of machine steel, case-hardened, and carefully brought to size. The cross-piece *C* has a steel plate *A* doweled and screwed to it, through which the broach slides, being guided by two keys which fit keyways milled in the side of the broach, which gives positive location for the cutters.

The bodies of the broaches *E* and *F* are each 8 in. long, case-hardened, straightened and ground, the tool-steel cutters being doweled and screwed into slots in the bodies. The holes in the cams are 0.875 in. and the keyway cut is 1/8 by 1/4 in. The teeth of the broach increase in size by 0.002 in. and the first one takes out a little over 1/16 in., leaving not quite as much more for the second one. These broaches have been used on over 2000 cams and are still in good shape.

USING SINGLE-TOOTH BROACHES

A rather unusual way of broaching out square holes in parts for pneumatic hammers is shown in Fig. 81. The piece *A* represents the class of work broached, and *B* a finished piece. Seven single-tooth broaches, shown in order at *D*, *E*, *F*, *G*, *H*, *I* and *J*, are used. The shanks of the broaches are splined, so as to fit the holder properly to follow each other in the correct position. One of the holders is shown in the press, and another near the broaches, both being lettered *C*. The work is done in the Cleveland plant of the Chicago Pneumatic Tool Co., and the press is a Watson-Stillman. Very fast work is done with these broaches, and the cost of making and upkeep is very low.

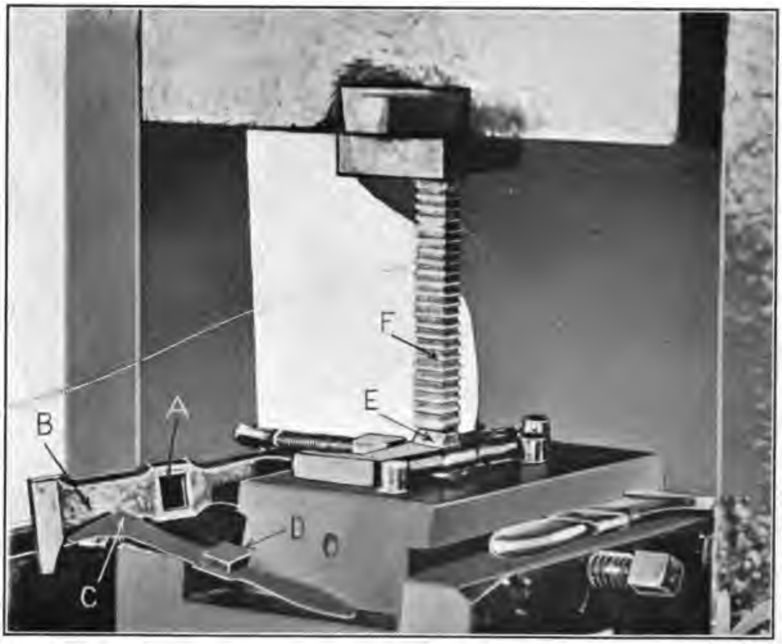


FIG. 79.—Broaching a wrench handle.

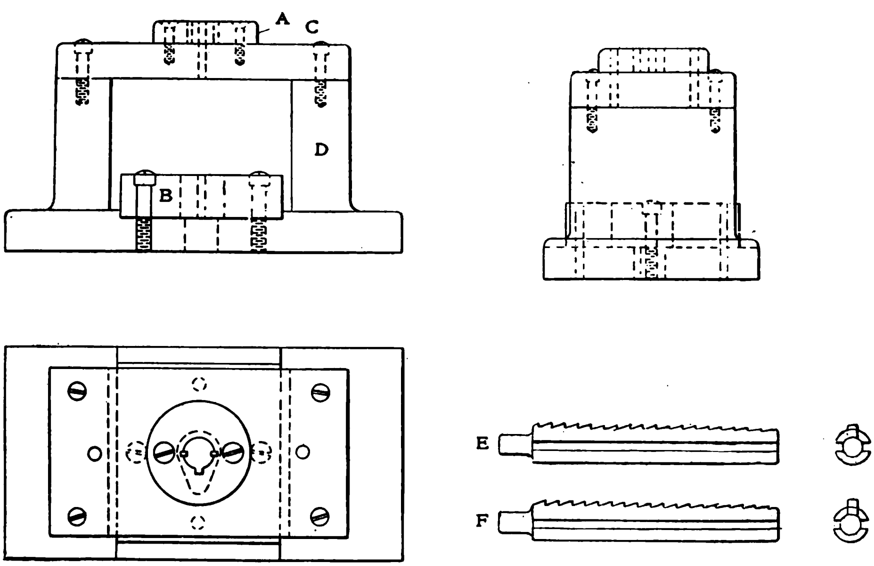


FIG. 80.—A sub-press for motor cams.

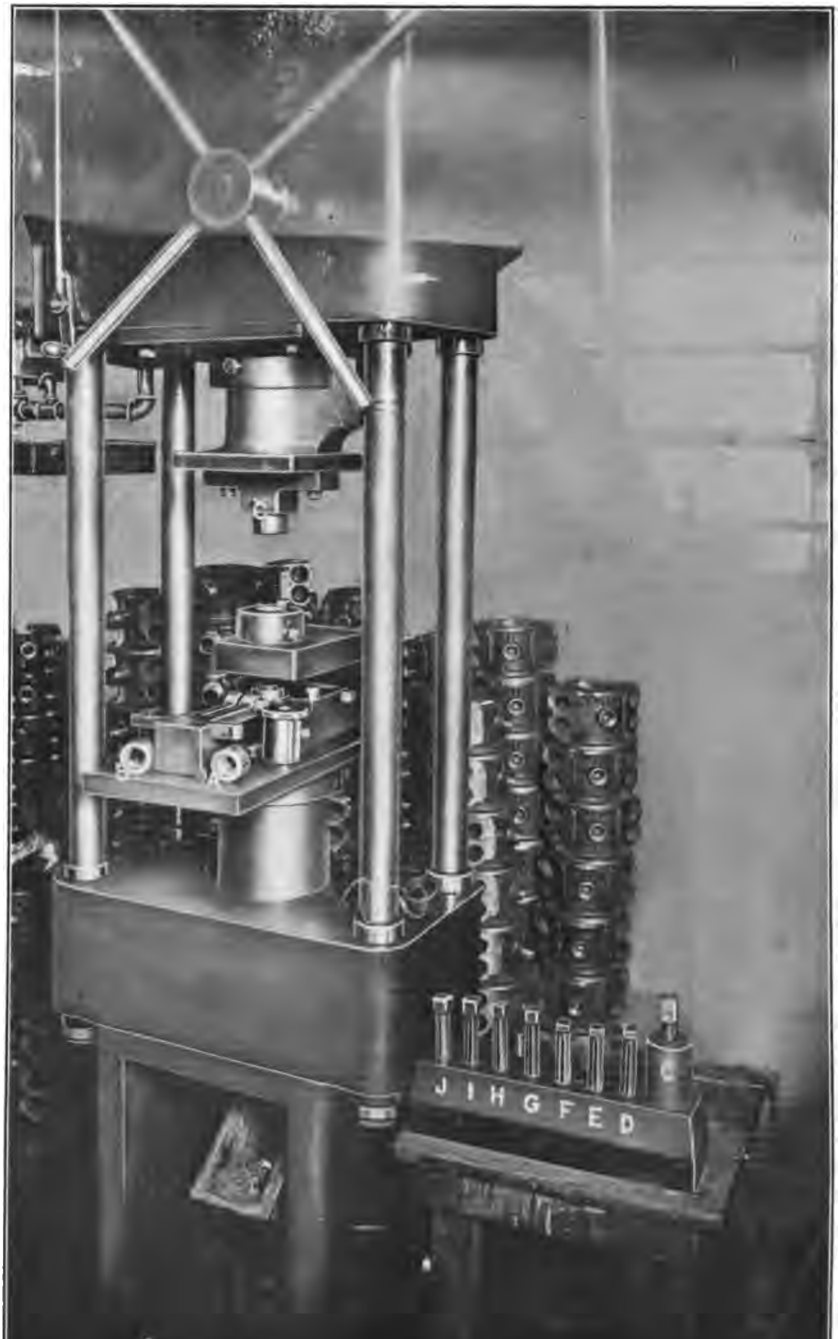


FIG. 81.—Using single-tooth broaches.

FIG. 82.—External broaches for splitting bearings.

EXTERNAL BROACHING WORK

The picture shown in Fig. 82 was obtained by Fred H. Colvin at the Ford Motor Co., Detroit, in 1913, and represents the practice of splitting bearings with an external broach. The bearings are first bored, reamed and turned on the outside. Next a broach with small cutters on opposite sides is forced through the inside. These cut *V*-grooves opposite each other through the bore. Using these grooves to locate the position of the bushing in the punch press, as shown in the illustration, the outside is cut so that it is an easy matter to split the halves of the bushings apart by the simple but ingenious device of inserting a split shell and forcing a taper mandrel through it. This avoids all injury to the inside bearing surface, as might be the case if a wedge were forced directly against the inside surface itself.

Some interesting external broaching operations are shown in Figs. 83 and 84. These are done in the shop of Frank Mossberg, Attleboro, Mass. Fig. 83 illustrates the cutting of the type of rack shown at *A*, these being a part of an invisible transom lifter. The job requires three settings in the broaching fixture, but is easily located so that the racks match up nicely. As will be seen by a close examination of the broach *B*, there are 16 broaching cutters, to divide the work up, avoid excessive chips and increase the life of the broach. Each broaching cutter is separate and firmly held between the spacing blocks shown. In this way any particular cutter can be replaced in case of accidental damage.

The broach slides in the opening of the broaching fixture, being well guided on three sides and providing ample room for the chips between the different broaching cutters. There remains little to be said in regard to its operation, the work being satisfactory.

Fig. 84, shows how the outside of the sliding jaw of a small monkey wrench is finished. The broach *A* works through the opening *C*, the back bearing against the plate *D*, which supports it while it is at work. The broach *B*, connected to the same holder as the broach *A*; slides through the opening *E* and is duly supported as shown. The work is held in the jaw *F*, operated by the crank handle *G*. The surfaces broached are indicated by the arrows at *H*.

THE MANDREL PRESS AS A BROACHING MACHINE

Paul Campbell, writing in the *American Machinist*, says:

We use a mandrel press to broach keyways in small cast-iron pulleys. These pulleys have a 3/32 by 3/16 in. keyway, 1 in. in length cut in them with a broach at a single pass, at the rate of one a minute.

The broach is made of a piece of tool steel 12 in. long, set into a machine steel bar 15 in. long and 1 1/16 in. in diameter, which is the size of the pulley bore. The teeth of the broach are 1/2 in. pitch and taper from 0.003 to 0.093 in.

We also cut a 1/16 by 1/8 in. keyway in a steel gear with the same-sized

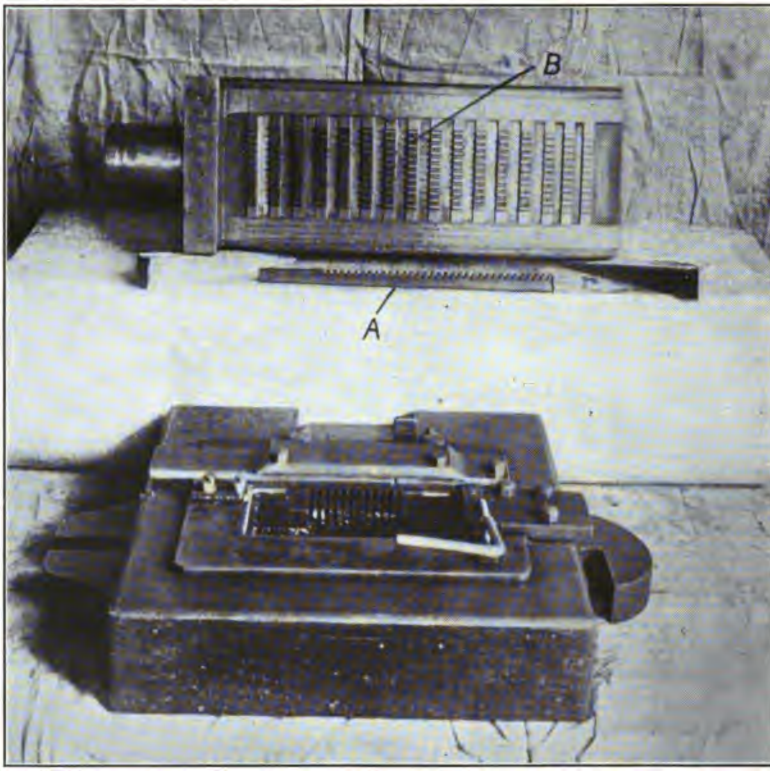


FIG. 83.—Rack-cutting broach and fixture.

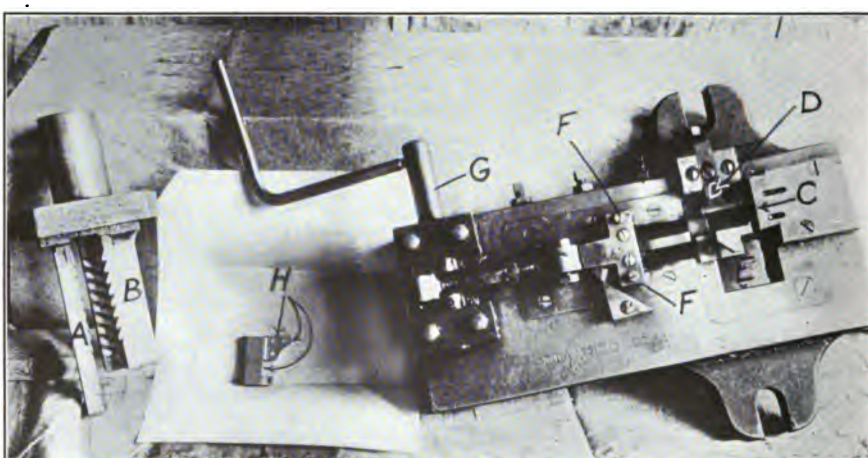


FIG. 84.—External broaching a wrench part.

hole, using two broaches, and the average time, including handling, is under 2 min. A cast-iron plate, counterbored to fit the pulley hub, is used to rest the work on, and no clamping is required.

MAKING USE OF A SUBPRESS

E. A. Ermold, in the *American Machinist* of May 16, 1912, writes:

More than a year ago the hand reamer, as a means of sizing and finishing round holes, was superseded in our shop by the broach, and since then a considerable saving has been effected in the cost per hole finished, and in addition the work produced has been so uniformly accurate that we are now able to manufacture our product on what is known as the interchangeable plan.

On about 50 per cent. of this class of work an accurate round hole is the starting point in the cycle of operations. In this connection when speaking of an accurate hole it is not amiss to state that the average reamed hole is very inaccurate when subjected to the critical inspection which our work now undergoes.

The principle involved in the broaching process is inherently more accurate for several reasons. In the first place it permits a more accurate method of presenting the work to the tool. To illustrate this, compare the manner of starting a hand reamer with the method shown in Fig. 85. The fixture shown is a subpress made very accurately and which, it will be noticed, is not subjected to any great stresses. The press itself takes the strains and it alone is deflected when under the cutting strain. The function of the subpress is to guide the broach and hold the work in alignment with it, the work being located by the previously reamed hole.

The subpress, with its interchanging bushings and adapters, is shown so clearly in Figs. 85 and 86 that a detailed description of the operation is not necessary. There are, however, a few details which it might be well to explain.

The subpress was made wide enough between the posts to take our largest piece of work and high enough to take the tallest piece and by using the subbases shown at *A* and *B*, Fig. 86, shallow pieces could easily be operated on.

The method of guiding the broach and locating the work is shown in detail in Fig. 87.

The guiding bushing *B* is a snug fit in *A*; *C* is the broach, the shank of which is smaller than the body; in practice it must be slipped into the bushing *B* before the latter is inserted in *A*. This procedure prevents injury to the cutting edges by being passed through a hard bushing. One end of the locating pin *D* fits the reamed hole in the work; the other end is made larger in diameter and fits a supporting block of hardened steel. The hole being larger than the broach allows it to pass through without the cutting edges coming into contact with it.

It will be noticed that the broach is not long enough to be forced through the work at one stroke of the ram; a pin is, therefore, placed on the broach at the second stroke to accomplish this. It was necessary to make the broaches short on account of the limits of the press. This is an advantage when making the broaches as they are easier to make when short.

Broaching and Reaming Cost Compared

The actual labor cost per hole when finished by the broaching method is slightly less than when hand-reamed, but the greatest saving is in the tool cost. When reaming the holes we found that we could not ream 25 holes to size with one reamer, but we have been able to broach 5000 holes with one ½-in. broach and all the holes were up to plug gage size. This broach was made for less than $5, which is something less than the 200 reamers necessary for 5000 holes under the conditions mentioned would cost.

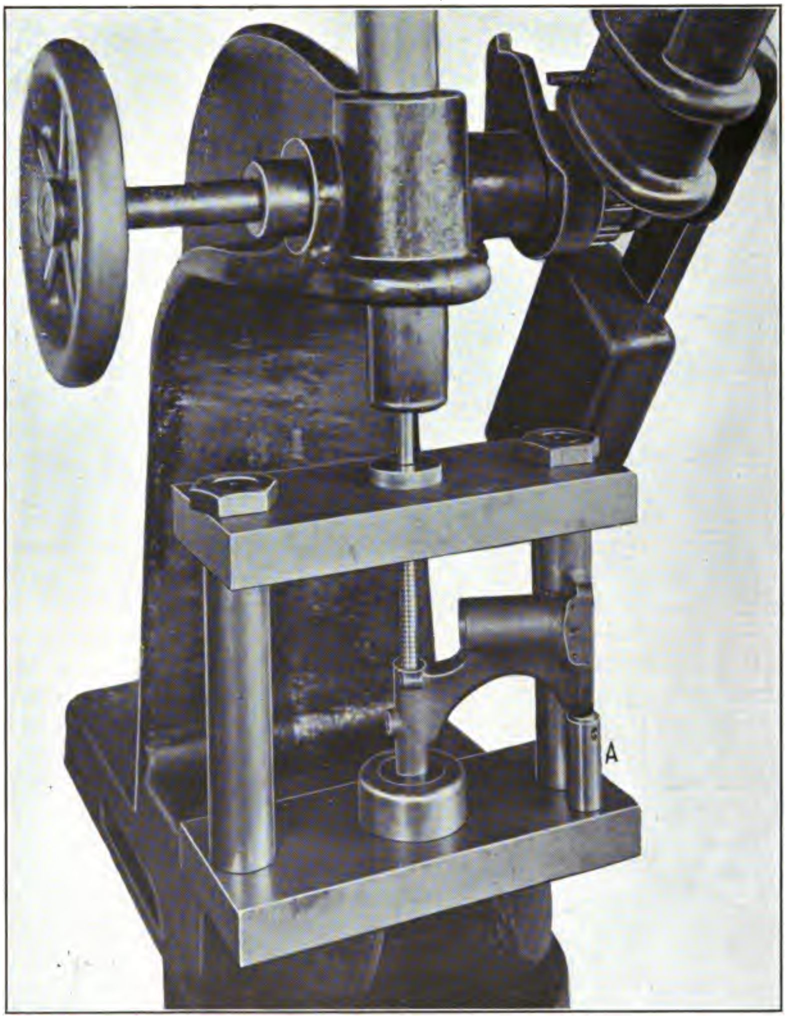


FIG. 85.—Supress in position in the hand press.

Another mandrel-press job is shown in Figs. 88 and 89. The work is done in the shop of the Dayton Electrical Manufacturing Co., Dayton, Ohio, and consists of broaching out the brush slots in small generator spiders. The broach is held by a setscrew in the ram of the press, and is guided by means of a jig bolted to the press table, as shown in Fig. 88. The work to be

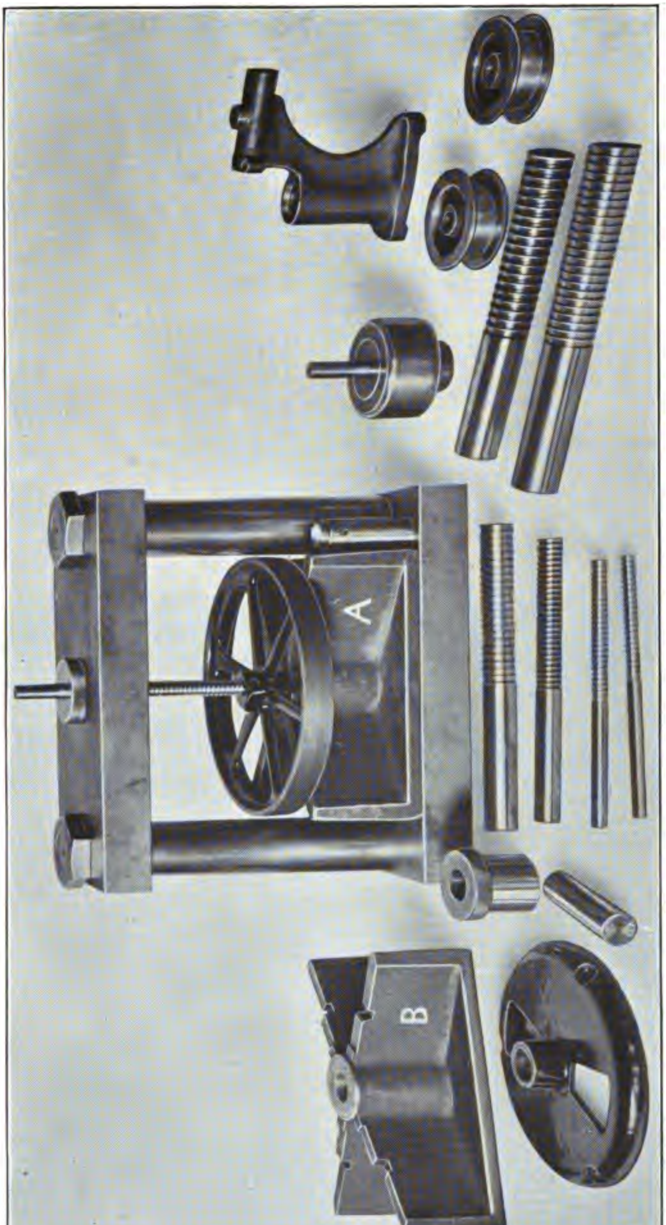


FIG. 86.—The tools and the work.

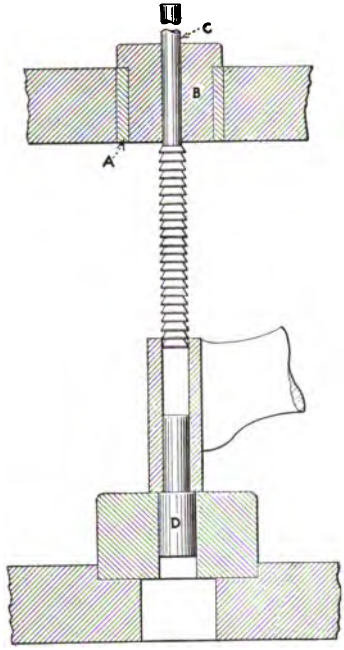


FIG. 87. — Details of the fixture.

FIG. 88.—The broaching fixture.

FIG. 89.—Work in place for broaching.

broached is placed in the jig as shown in Fig. 89, and the brush slots are finished at one stroke of the press ram.

A special fixture and broach are shown in Fig. 90. The brass guide bushing *A* forms part of a lens-grinding machine. It is about 8 in. long and 1½

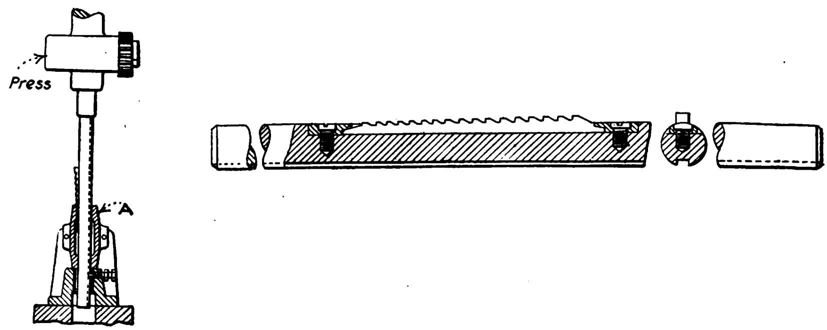


FIG. 90.—A special broach and work fixture.

in. in diameter, and is chambered out so that the keyway in it is in two sections, each 1½ in. long, 1¼ in. wide and 3/16 in. deep. The broach is interesting from the way the cutter is held in place by the two toe pieces. A spline is cut in the back of the broach bar, to guide it.

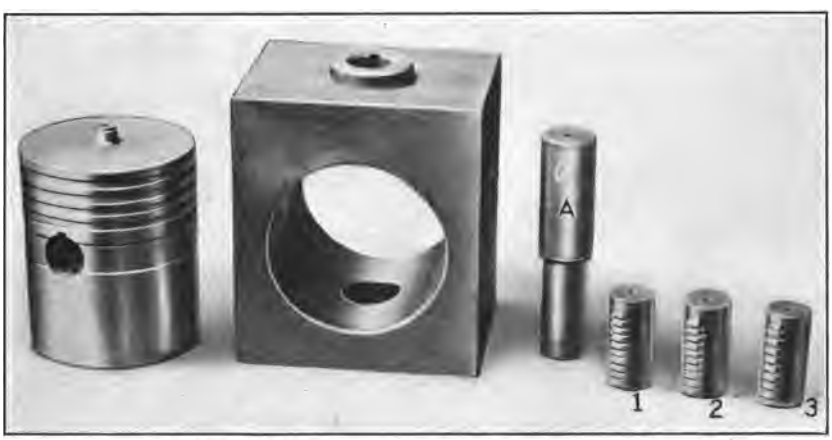


FIG. 91.—Jig and tools for broaching wristpin keyway.

BROACHING WRISTPIN KEYWAYS

The hollow-steel wristpins of the pistons used on Fiat motors made in Poughkeepsie, N. Y., are keyed and pressed into place and secured by a taper-end setscrew, which in turn is secured by a cotter pin. The keyway cut in one end of the wristpin hole is broached out in a hand press, using the broaches and jig shown in Fig. 91.

In using this jig, the piston is slipped into it, till the wristpin hole is approximately under the bushed hole. The bevel-end pin *A* is then thrust down through the bushing into the wristpin hole, lining the two up, so that the first broach may be easily inserted in the bushing, with its pilot in the wristpin hole. This broach is then pushed through and is followed by two others, which cut the keyway to size.

A HAND-BROACHING PRESS

A hand press designed by A. C. Pletz, is shown in Fig. 92. This was not intended for broaching keyways over 1/4 in. in size, or 2 in. long. Where a number of holes the same size are to be keywayed, the broach holder may be made the same size as the hole, or if desired, an eccentric work bushing may be used and the broach holder made to slide through it. The broach is made of rectangular stock and is set into a slot in the holder, as shown. The capstan wheel is fastened to a threaded sleeve shouldered at *H*. The screw *C* has a keyway cut its entire length, and a key is placed at *G* to prevent the screw and broach from turning when being run down.

While the cut shows the screw cut with a right-hand thread, it would probably be more convenient for the operator to have it left-hand, as then the movement would be more natural when forcing through the broach. Though originally intended only for small work, this form of press can easily be made for larger work, by varying its proportions.

TURRET BROACH FOR A MANDREL PRESS

Hexagon holes are broached in cylinder caps in a mandrel press, using the turret broach shown in Fig. 93. The blind holes in the caps are chambered out at the bottom for clearance, and then the turret broaches are forced in, one at a time. The pin *A* serves to locate the broaches correctly and also to lock them in place during the cut. The "teeth" of the broach increase about 0.002 in. in size.

BROACHING KEYWAYS TO A SHOULDER

The method used to broach out small brass parts to a shoulder is shown in Fig. 94. The part is slipped down into the holder on the bed of the mandrel press, the holes in the flanges fitting over pins in the bottoms of the slots in the sides of the holder collar. A steel collar that fits the turned body of the casting is then placed over it and locked down by the two thumb-screws shown in the sides of the holder. The bored hole in the brass casting is, of course, chambered out where the two keyways end, so that the broaches can make a clean cut.

The broaches are double-end cutters set into separate bars in a sort of turret. There are six double cutters in all, each one being larger than the preceding one. The bars that hold the cutters fit the bored hole of the casting and act as pilots for them. The indexing is done with the left hand as the right operates the lever.

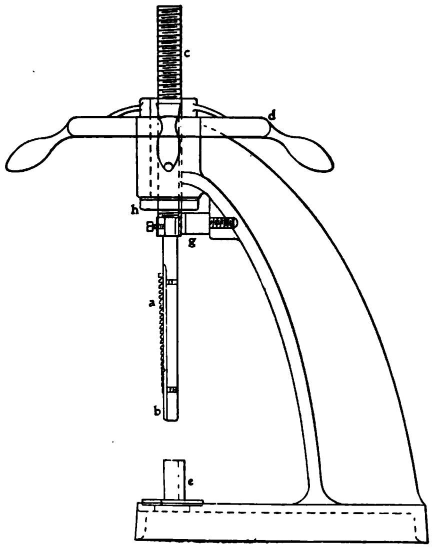


FIG. 92.—A hand broaching press.

FIG. 93.—Turrent broach for a hand press.

CUTTING OIL GROOVES IN EIGHT HOLES AT ONCE

Oil grooves are cut in the push-rod guide holes, in Ford cylinder castings, by means of small broaches forced through eight at a time, in an ordinary mandrel press fitted as shown in Fig. 95. The teeth of the broaches are cut with a slight spiral, so as to give the oil grooves the proper twist.

The cylinder casting is placed upside down on the table of the press, and the operator places a broach on the inside end of each hole, where it rests on the teeth which are to do the cutting. Having the eight broaches in position, the handle of the press is brought down, and the eight studs in

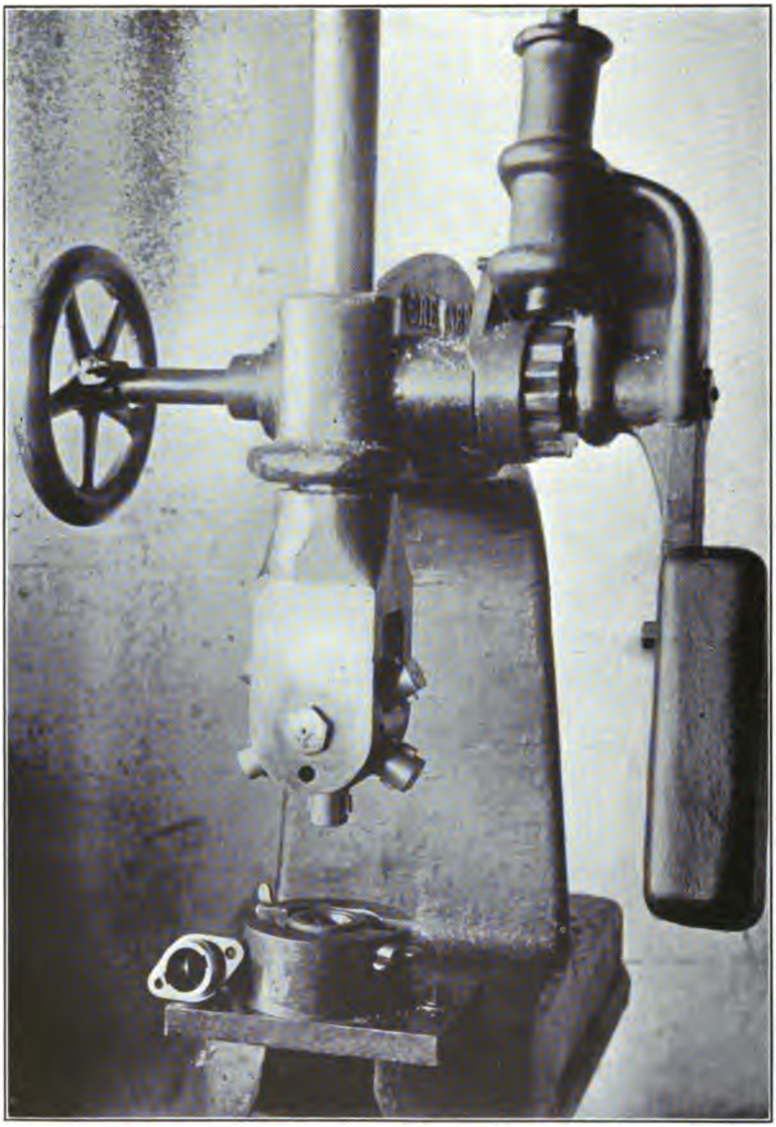


FIG. 94.—Broaching keyways to a shoulder.

the special head *B* force the broaches through and out of the holes. It will be noted that these studs are not all the same length, and, therefore, do not all commence work at once, making it easier to force the broaches through, though the cuts are not heavy, and the power required is not great in any case.

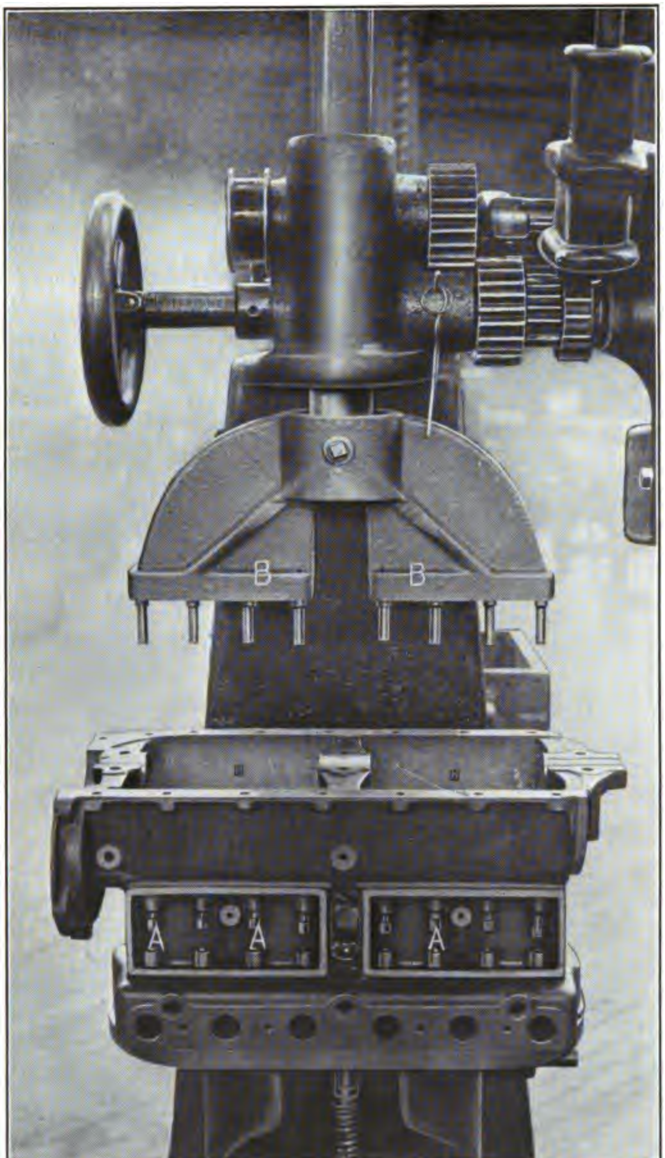


FIG. 95.—Cutting oil grooves in right holes at once.

In the positions in which the broaches are shown at A, they are about to drop through, to be picked up by the operator and used again. The distance between the projecting lugs, which form the guides for both the valve stems and the push rods, gives an idea of the length of the broaches and of the simplicity of the whole proposition.

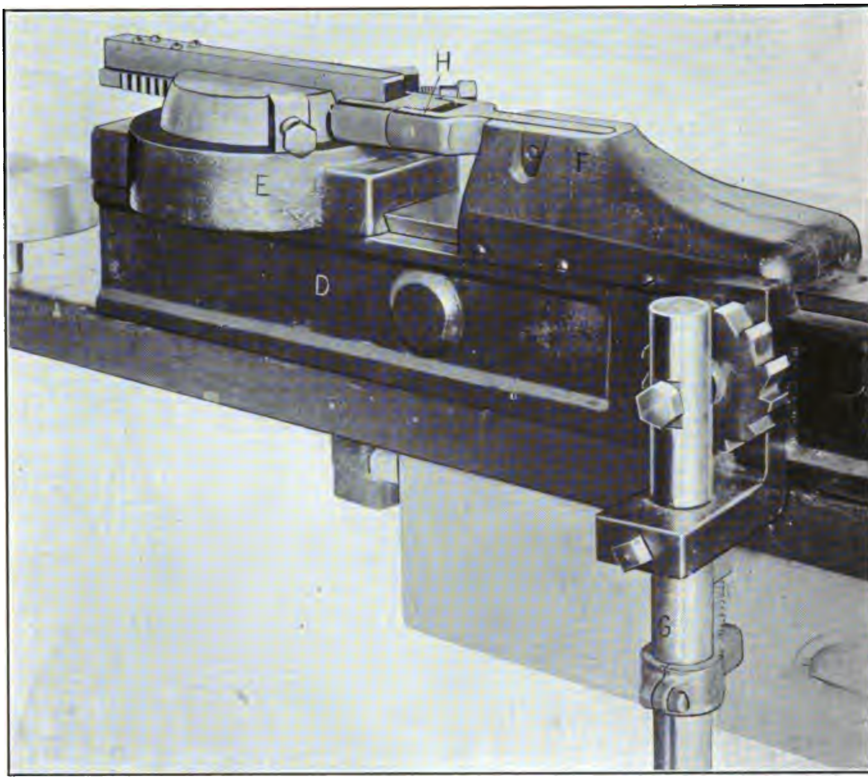


FIG. 96.—Horizontal hand broaching machine.

HORIZONTAL HAND-BROACHING MACHINE

While the machine shown in Fig. 96 is not a push-broaching machine, it belongs among the hand machines and may as well be shown here as

FIG. 97.—The adjustable broach used.

anywhere. In fact with slight modifications, it would make a good hand press for numerous push-broaching jobs. This machine was made and is used in the shop of Adolph Muehlmatt, Cincinnati, Ohio. It is used to broach out the jaw slots in engraver's ball vises. These slots are first milled to approximate size and then finished by broaching. The device consists of a base *D*, a work holder *E*, a slide *F* for drawing the broach through the work, and a long lever *G* for operating the slide through the medium of a pawl and ratchet, and a rack and pinion under the slide. The broach used is shown in Fig. 97, and is of T-section to correspond to the T-slot wanted. There are two notches in the shank end of the broach which are adapted to be engaged by pins in the coupling member *H*. The latter is attached to the top of the slide *F*, and its outer end is pivoted to the body so that it may be swung up to clear the end of the broach or dropped into the horizontal position represented with its projecting pins engaged with the notches in the bottom of the broach.

The turntable to be operated on is dropped into a seat in the fixture *E*, the broach is slid into the T-slot from the rear, and the coupling member *H* is swung down to engage the end of the broach and at the same time align the work with the slide *F*. The two setscrews in the fixture *E* are then tightened sufficiently to prevent the work from moving, and as these screws take a bearing against the rounded upper portion of the turntable they hold it firmly down in its seat. The broach is now pulled through by manipulation of the long lever. The connection between the lever and pinion stud under the slide being by pawl and ratchet, the lever is adjustable immediately to any angle or height best suited to the operator, and can thus be operated through the arc found most convenient and effective.

The broach itself is so constructed as to admit of a reasonable amount of adjustment to facilitate holding to standard width. A slot is milled in the body for over half the length and the broach in two sections is attached to the metal at each side of the slot by screws passing down from the top. A wedge of very slight taper is inserted in the slot and gives the necessary degree of expansion for the broach sections.

BROACHING ON A SHAPER

The cuts, Figs. 98 and 99, illustrate the way the Smith & Mills Co., Cincinnati, cut keyways in small steel gears. An open box casting *A*, having a hole bored in the front wall for the slotted mandrel *B*, on which the gear *E* is placed for keyseating, is bolted to the knee. The cutter blade *C*, about 4 ft. long, 1 in. wide, and of the thickness required by the width of the keyway, is drawn through the gear by the successive strokes of the ram. The teeth on this broach are so made that each tooth removes about 0.002 in. of metal. The ram motion is transmitted to the cutter by the notched bar and the latch *H*. The notches on the bar are 6 in. apart and the stroke of the ram is set to a movement slightly more than this, or to 12 in. if the cut is not very wide or deep. To pull the cutter 4 ft. on the short stroke, which is used for the larger keyways, requires eight strokes. The thrust of the casting is taken directly by the column through two screws, one of which is shown

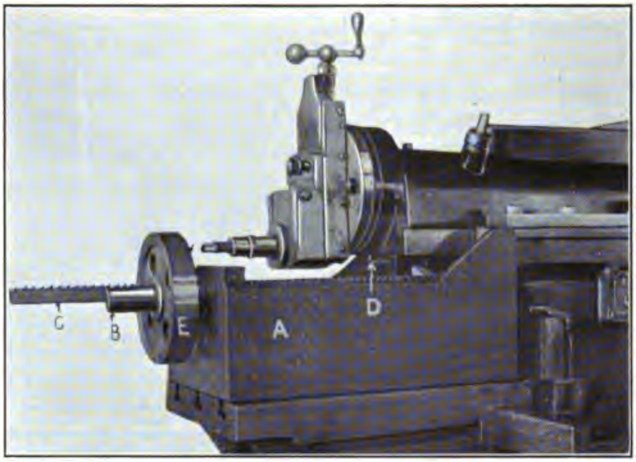


FIG. 98.—Shaper broaching fixture.

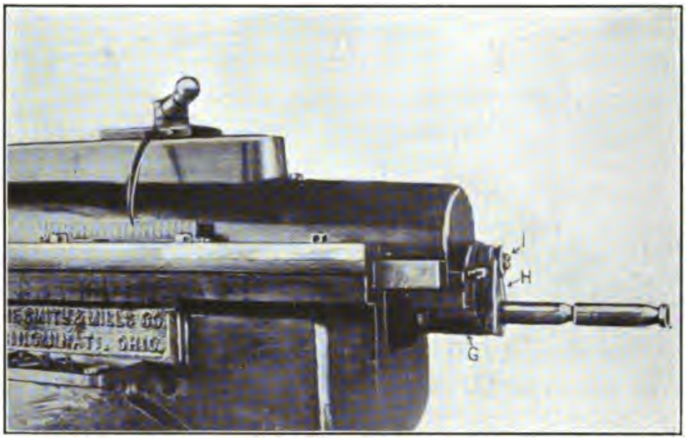


FIG. 99.—View of draw bar and latch.

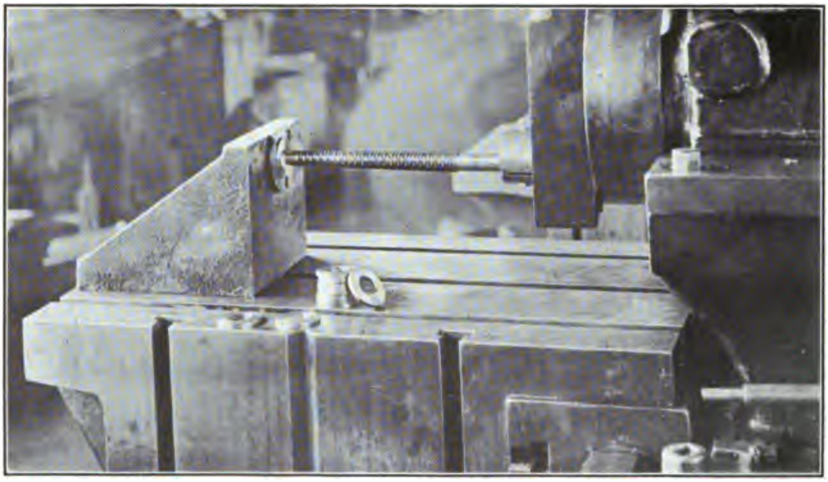


FIG. 100.—Broaching out D-washers.

at *D*. Guides like *G*, bolted to the under side of the ram, support the bar but do not interfere with the regular use of the shaper. The latch *H* consists of two pieces of flat steel reduced to half thickness where they overlap, and which are pivoted on the screw *I*, on which they swing freely. When the ram moves forward, the leaves swing apart and drop into one of the notches of the bar on the return stroke, the action being the same as that of a pawl.

The method used by the Cincinnati Shaper Co. to broach out D-washers on a shaper is shown in Fig. 100. The angle plate used to hold the washers, which are first drilled out, has a hole through it for the broach and is also slotted on the face just enough to hold the washer in the proper position. The broach is held in a sort of split collar in place of the usual clapper box, being clamped in by means of a setscrew. As a washer is broached it is pushed back onto the shank of the broach, others being dropped into place in the slot of the angle plate by hand at each stroke of the ram, till the shank of the broach is full, when the setscrew is loosened, the broach removed and the washers dumped into a box. The broach is then replaced and the operation repeated.

A SURFACING OPERATION

A pair of broaches laid on parallels and clamped in a shaper vise were used in one shop to finish off the sliding surfaces of wrench jaws, in the absence of a suitable miller. The part of the wrench jaw to be finished is shown at *A*, Fig. 101, and the two broaches used at *B–B*. The piece *C* was clamped in the tool post of the shaper to push the jaw over the broaches, and as the broach teeth were properly proportioned, the job was done at one stroke of the shaper ram.

A SHAPER TURRET

An interesting operation on a shaper is shown in Fig. 102. This is done in the Billings & Spencer shop, Hartford, Conn., and consists in broaching the hole for the sliding jaw of an adjustable S-wrench. Two parallel holes are first drilled through the forging and then the bridge between them is removed by a species of end mill.

The forging then goes to the shaper. The head *A* carries either two or three tools *B*. For this size hole two tools are used; the seat *C*, it will be observed, has no tool in it. A trip fastened to the frame of the shaper lifts the indexing pin on the return stroke of the ram and permits the head to be rotated to bring the next tool into working position. The work is secured in a fixture *D*.

BROACHING ON A PLANER

In a short article, H. B. McDermid says:

In manufacturing one type of Parsons turbines the problem of cutting a large number of special slots in connection with the blading work was put up to the boss

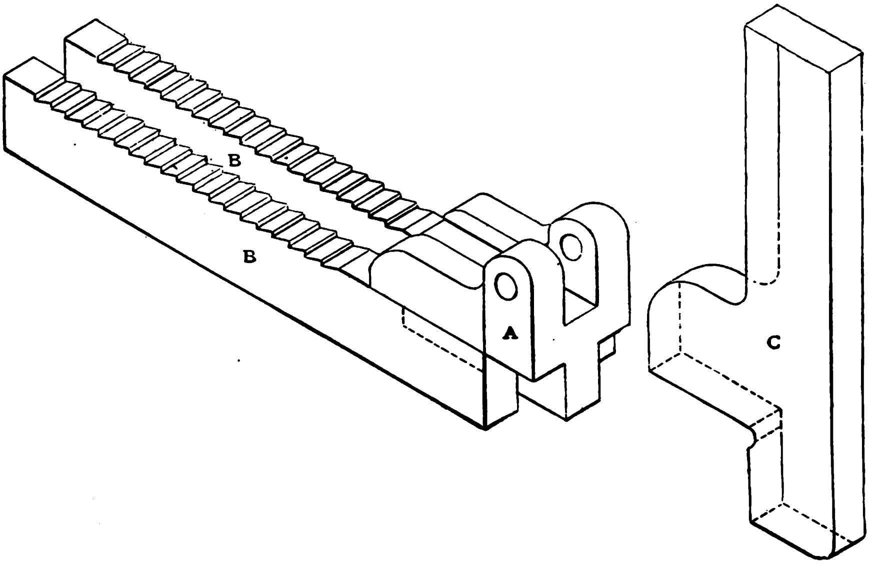


FIG. 101.—A surfacing operation.

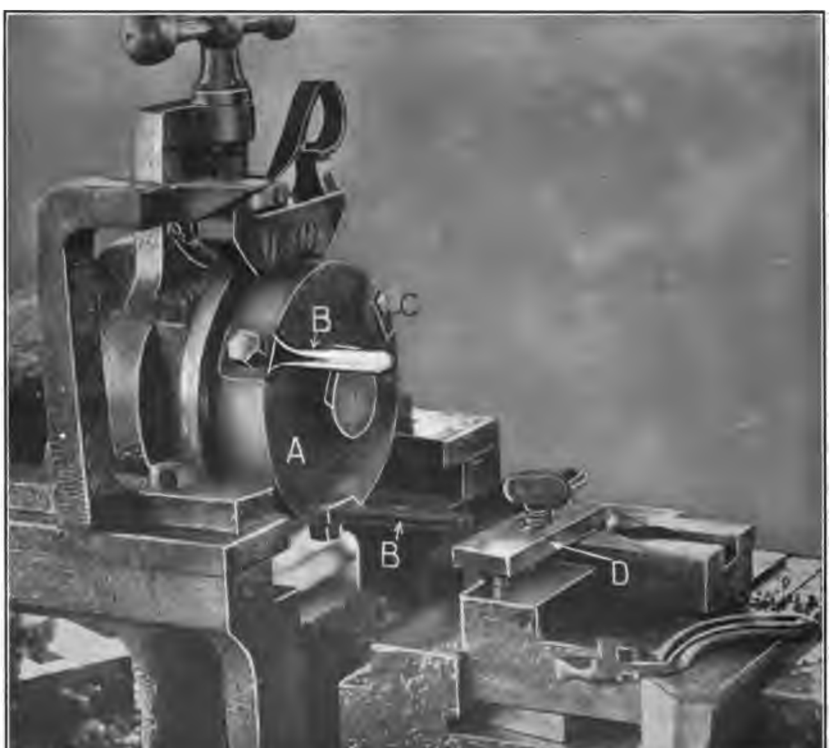


FIG. 102.—A shaper turret broaching attachment.

tool maker for solution. The stock was brass or bronze in the form of disks about ¼ in. thick, averaging perhaps 30 in. in diameter. Each disk contained a large number of slots; and as there were quantities of the disks to be machined, it was important to devise some method that would permit rapid production.

Fig. 103*A* shows the design of the piece, and an enlarged view of the special slots to be cut. The disk was mounted on a heavy disk or jig of a diameter enough smaller so that the supporting jig or fixture just cleared the bottoms of the slots of the finished piece.

The whole contrivance was then mounted upon the crossrail of a planer, and a spacing device was connected to the regular planer feed system so that with each stroke of the planer platen the work was revolved through an angle equal to the spacing of the slots and rigidly held in place during the cutting stroke.

The multiple-toothed broach was clamped in place on the planer bed. This broach was made in sections, the first tooth being the shortest and the line of the points of the others forming an acute angle with the planer platen, so that each tooth would remove a chip from the stock and the last one would finish the slot to the desired depth. The section *A* of the tool had side points parallel to the planer bed, for cutting the side notch *A* in the slot. Its first tooth started the slot, and its last completed the work to finished size. Thus with every stroke of the planer a slot was completed to size, the tool withdrawn, the piece revolved by the feed mechanism through the proper angle, and another cycle of operations started.

The work, being mounted on a tool head, could quickly be adjusted both horizontally and vertically; and once set at the proper height with its vertical center line over the tool, the work could be completed very rapidly, the changing of blanks necessitating the only pause in the job.

It will be noticed that the small side slot complicated this tool problem somewhat, as for a plain slot several other methods might have been used. In this instance only one block was machined at a time, but with a more rigid fixture several might be machined.

In another short article, Charles H. McCarter says:

The illustration shows a broaching operation on igniter stops for gas engines, which may be applicable to pieces of a like nature in shops not equipped with a broaching machine, or where the quantity of work turned out does not warrant the expense of installing one.

In Fig. 103*B* is shown the drop-forged igniter stop before broaching. It is first drilled and turned true on the sides preparatory to broaching. The work is then placed in the fixture shown and located in its proper position by the two pins. A V-block, set directly in front of the fixture, furnishes the seat for the stop and also acts as the guide for the broaches.

The first broach is placed in position in the V-block, and the stroke of the planer is adjusted. Then the planer is started, forcing the broach through the work by means of a hardened block of tool steel fastened on the front of the head.

Three broaches are used to bring the hole to size. They are made with a pilot on the end with about 0.002-in. clearance in the work. Each broach is made with a radius on the edges, the radius getting smaller toward the rear end. The fina broach is made with a small radius gradually decreasing toward the back until about

1 in. from the end; the rest of the cutting part of the broach is left with perfectly sharp edges. The broaches are made slightly taper on the rear end, as the blows

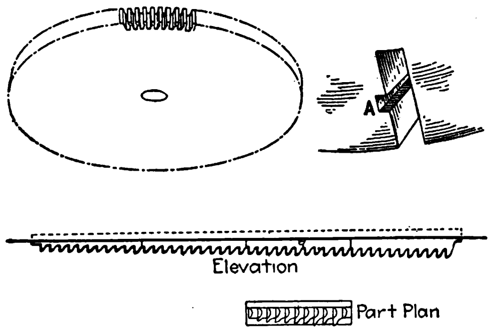


FIG. 103*A*.—Turbine drum and broach.

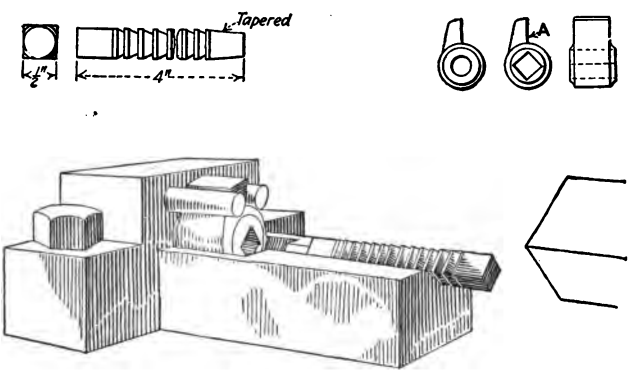


FIG. 103*B*.—Igniter stop, fixture and broach.

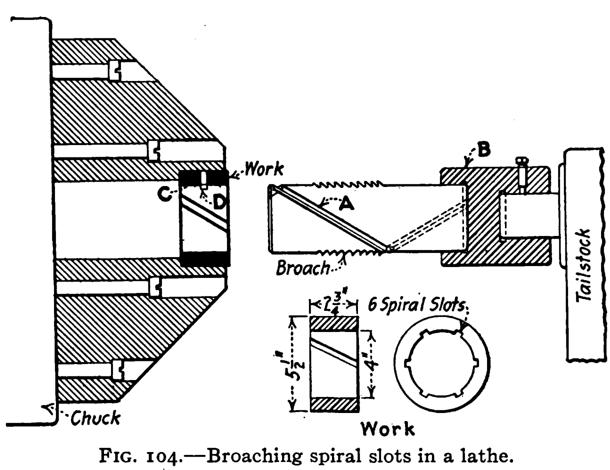


FIG. 104.—Broaching spiral slots in a lathe.

received tend to upset them a little. The speed of the planer is made considerably slower than usual, in order not to break the tools and to give them time to cut.

This operation is entirely satisfactory, and the pieces are done at a fair rate of speed. After the broaching operation the pieces are put on a square mandrel, five at a time, and a milling cut is taken at *A*, bringing this face correct with relation to the square hole.

BROACHING SPIRAL SLOTS IN A LATHE

An adaptation of the lathe to broaching a keyway in a bushing is shown, Fig. 104. These bushings were required in small quantities and the keyway had to be an accurate spiral.

To accomplish this a number of short broaches of slightly increasing diameter were used, one of which is shown in position; and in these broaches a spiral slot *A* was cut.

The work is held in special chuck jaws, as shown, which give clearance in the back to permit the broaches to go through the work. By throwing in the back gears with the bolt that connects the gears to the pulley locked up for direct driving, the spindle of the lathe is locked so that it will not revolve. Over the tailstock spindle a sleeve *B* is placed. In the center of the work to be broached a hole *C* is drilled, and in this hole is driven a pin *D*. For broaching, the shank of the broach is placed in the sleeve *B*, the teat of the broach is guided by hand into the hole of the work, while the slot *A* is caused to engage the pin *D*. Then by turning the handwheel on the end of the tailstock the broach is forced through the hole in the work and made to revolve as the spiral groove travels along the pin. Thus the keyway is a true spiral, following the groove. Each broach will follow the path of its predecessor, as the broach teeth are cut with due regard to their relation with the groove. It is necessary on this work to remove the part from the chuck after each broach has been passed through, in order to withdraw the broach.

A TURRET BROACHING MACHINE FOR GUN-RECOIL VALVES

A gun-recoil valve and casing are shown in Fig. 105. These are used to take care of the recoil of the guns by means of oil flowing through the ports. The special machine used to drill and broach out the ports is shown in Fig. 106. Each valve has 1382 holes, 0.140 in. in diameter, drilled through the wall. Where the rectangular ports are to be broached, the holes are drilled as close together as possible. The walls are 7/32 in. thick and the valves are 4 1/16 in. in diameter.

The work is mounted on the index centers *B*, the index flange being drilled to receive the index pin *H*. Behind the flange is a worm gear and worm operated by the handwheel *C*, when it becomes necessary to shift to the next row of holes in circular spacing. For longitudinal spacing a precision screw *G*, cut by Brown & Sharpe, is used. The carriage *C* carries the driller and its motor at the back, while on the front is mounted the turret. Secured in the turret proper are the seven broaching tools *D*, which are of the single point, increasing-size variety. The broaching is done by hand, the handwheel *E* giving ample power.

This machine is used in the shops of the Detrick & Harvey Machine Co., Baltimore, Md., on government work.

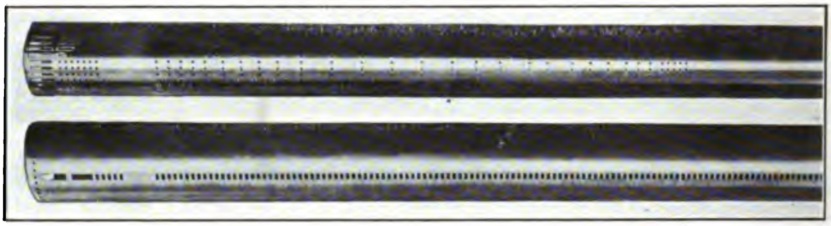


FIG. 105.—Gun recoil valve and casting.

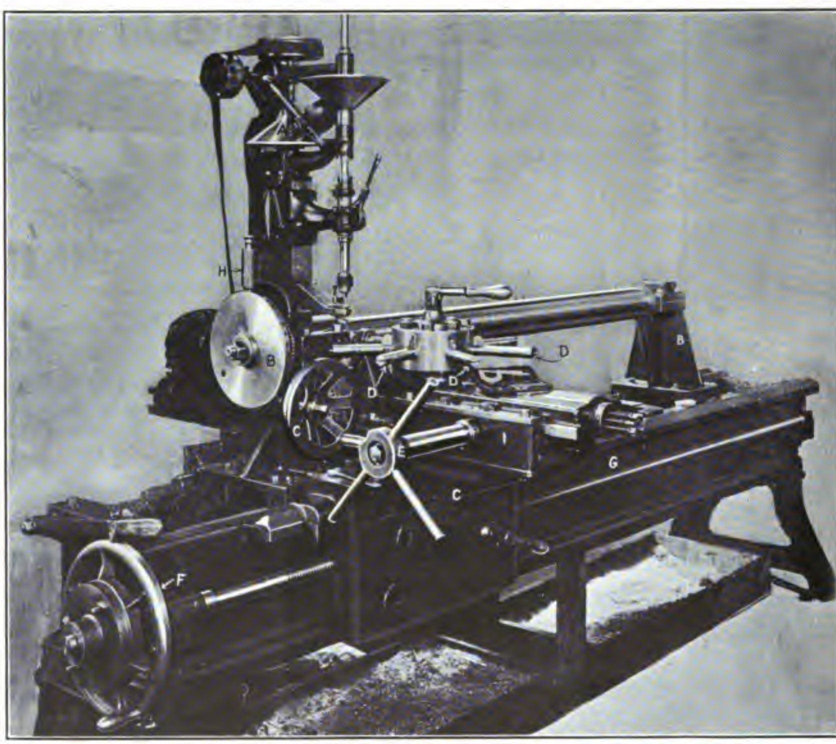


FIG. 106.—Gun recoil valve drilling and broaching machine.

TURRET MACHINE FOR SMALL SQUARE HOLES

A machine working on the same principle as the one just described, is shown in Fig. 107. It is used for broaching out holes from 1/4 to 1/2 in. square and about 2 in. long, in forged steel. These holes are drilled on a slant, so that it would be almost impossible to broach them out with a single broach of the usual type without the breakage being excessive. The holes are drilled out first with a full-sized drill, and then they are squared out with five tools held in the turret. The first three tools are octagonal in shape, each a little larger than the preceding one, and the fourth is square, and almost full size, while the fifth is full or finishing size. Owing to the tough-

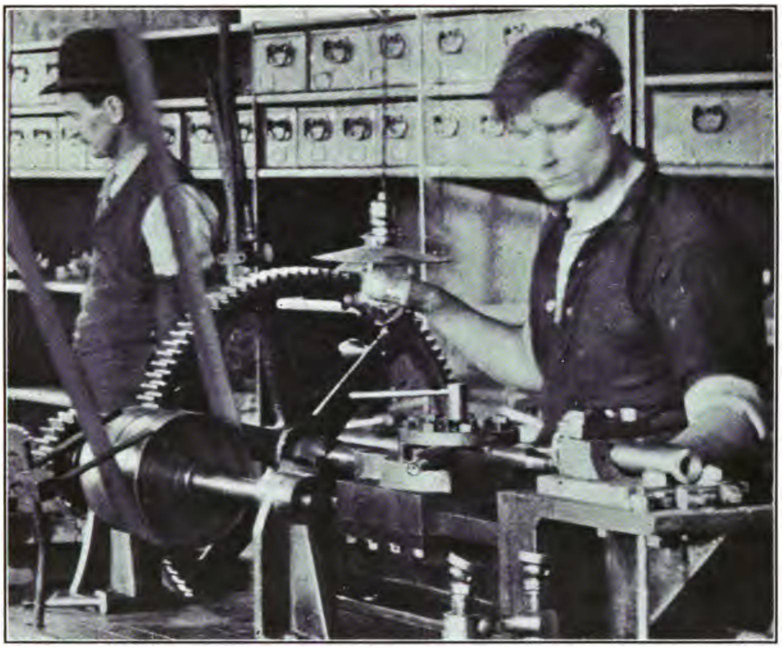


FIG. 107.—Turret machine for small square holes.

ness of the steel used in the forgings, considerable force is required to push the cutters through, and to do this the turret is fed forward by means of a gear-operated screw. The pinion on the pulley shaft is made so that it can be easily slipped out of mesh with the screw gear, enabling the operator to run the turret back or set it where wanted. The work is held in a sort of pillow block, set on an angle plate bolted to the end of the machine, and the whole machine rests on a heavy wooden table.

CHAPTER V

THE DESIGN OF PULL BROACHES

In making any type of broach a number of things must be taken into consideration, such as the material to be cut, length of the work, amount of stock to be removed and the shape of the work. The last in order to decide upon the manner of holding and whether special fixtures will be needed. The length and number of broaches will depend largely on the amount of metal to be removed, the size of the work and the machine available. Hard and fast rules are not yet developed for use under all conditions, and many of the successful tools have been evolved through a series of painful and costly experiments. There are a few formulas and general rules that may be used as a basis, however, for ordinary broach designing, and their use will often save considerable worrying on the part of the designer. Warning must be given here to the sticking to any certain formula in laying out broaches for different kinds and sizes of work, and the formulas given farther along in this chapter must be used with considerable horse sense. In a large number of cases it is far better for a shop to send details of their work to firms making a specialty of broach making, and depend upon their judgement and experience to furnish them with satisfactory tools. There are cases, however, where circumstances do not make this possible, or preferable to the management. For these cases data will be found in this chapter sufficient to enable the designer or toolmaker not to go at the job blindly. One big thing to keep in mind, when laying out the tooth pitch or spacing, is that differential spacing should be resorted to wherever there is any tendency to chatter, on the same principle as the differential spacing of reamer teeth, which is now practically universal. Broadly speaking, the pitch of broach teeth should increase as the length of the hole increases, in order to provide sufficient chip space. The pitch should, within certain limits, be as coarse as possible without weakening the broach. At least two teeth should be in contact with the work at all times. If the work is too thin for this, some method must be devised of guiding the broach, or else, as in the case of washers, a number of pieces are broached at once, the washers being held so as to represent a practically solid hole. If teeth are too closely spaced, they may either choke up, or require too much power to pull through the work, either case resulting in a broken broach.

In calculating the pitch of broach teeth for ordinary work, a fairly good rule is: The pitch of the teeth equals the square root of the length of the hole multiplied by the constant 0.35. Expressed as a formula, this is: $P = \sqrt{L} \times 0.35$. For convenience in calculating the pitch, R. C. Haynes has compiled Table I from this formula, giving the pitch of broach teeth for holes from 1/4 to 12 in. in length. The table shows the theoretical length and the nearest fractional dimension to which it is practical to make the teeth.

TABLE I.—PITCH OF BROACH TEETH

Length of hole in work, in.	Theoretical, in.	Practical, in.	Length of hole in work, in.	Theoretical, in.	Practical, in.
1/4	0.175	3/16	4	0.700	11/16
3/8	0.214	7/32	4 1/4	0.721	23/32
1/2	0.247	1/4	4 1/2	0.742	3/4
5/8	0.277	9/32	4 3/4	0.763	3/4
3/4	0.303	5/16	5	0.782	25/32
7/8	0.327	5/16	5 1/4	0.802	13/16
1	0.350	11/32	5 1/2	0.820	13/16
1 1/8	0.371	3/8	5 3/4	0.839	27/32
1 1/4	0.391	13/32	6	0.857	27/32
1 3/8	0.410	13/32	6 1/2	0.892	29/32
1 1/2	0.429	7/16	7	0.926	15/16
1 5/8	0.445	7/16	7 1/2	0.959	31/32
1 3/4	0.463	15/32	8	0.990	1
1 7/8	0.479	15/32	8 1/2	1.020	1 1/32
2	0.495	1/2	9	1.050	1 1/16
2 1/4	0.525	17/32	9 1/2	1.079	1 3/32
2 1/2	0.553	9/16	10	1.106	1 3/32
2 3/4	0.580	19/32	10 1/2	1.134	1 1/8
3	0.606	19/32	11	1.160	1 5/32
3 1/4	0.631	5/8	11 1/2	1.187	1 3/16
3 1/2	0.655	21/32	12	1.212	1 7/32
3 3/4	0.678	11/16			

CHARTS FOR BROACH DESIGN

The charts herewith were plotted by L. A. Williams to assist in arriving at quick results when used in connection with the design of broaches.

The chart, Fig. 108, gives the difference in area between a hexagonal figure and an inscribed circle, and between a square figure and its inscribed circle. It also gives the corresponding cubic measurement for any length of work up to 10 in. The method of using the chart is as follows: Starting at the left-hand side of the line opposite the desired inscribed circle diameter, follow this line toward the right until it intersects with the curved line representing either the hexagonal figure or square, as the case demands. Then from this point follow the intersecting vertical line to the bottom of the chart, where the area is given in square inches. To read cubic inches follow the vertical line to where it intersects with the angular line representing the length of work; then from this point follow the horizontal line to right-hand side of the chart, where the cubic inches may be read.

The chart, Fig. 109, is intended to give sectional area and cubic inches of metal removed for multispline holes, such as are used in gears on automobile transmissions. (The results derived from this chart are not strictly correct, but the error is negligible.) The procedure in using this chart is similar to that given for Fig. 108. The lower angular lines represent the total length of all the splines added together; that is, four splines in a piece 3 in. in length equal "12 L" on chart.

The third chart, Fig. 110, deals with the relation between pitch and number of teeth, length of taper, thickness of chip per tooth and the amount of taper. This chart was made up primarily to give the thickness of chip per tooth, as given by the right-hand group of angular lines, but it will be

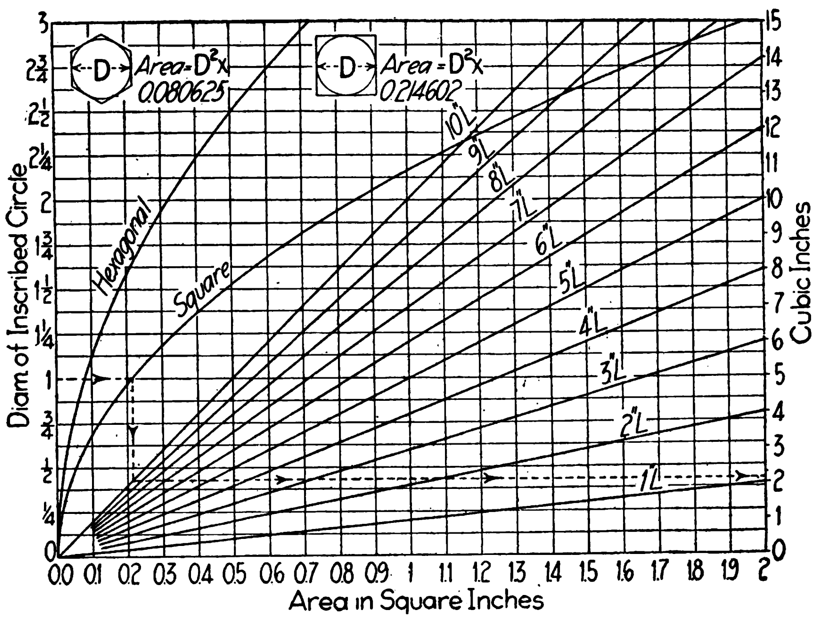


FIG. 108.—Chart to obtain difference between a hexagon or square and inscribed circle.

evident that this may be used as a starting point if so desired, and the other required quantities plotted from it.

DEPTH OF CUT PER TOOTH

Obviously, while the foregoing tables and formulas give a good foundation for calculating the pitch of broach teeth they cannot be followed blindly or for all metals or conditions without making due allowance. The examples of actually made broaches and the detailed experience and directions of practical shop men, which will follow in this chapter, will do much to give the designer a safe working guide to be used in conjunction with the foregoing data. The amount of metal that each successive tooth should re-

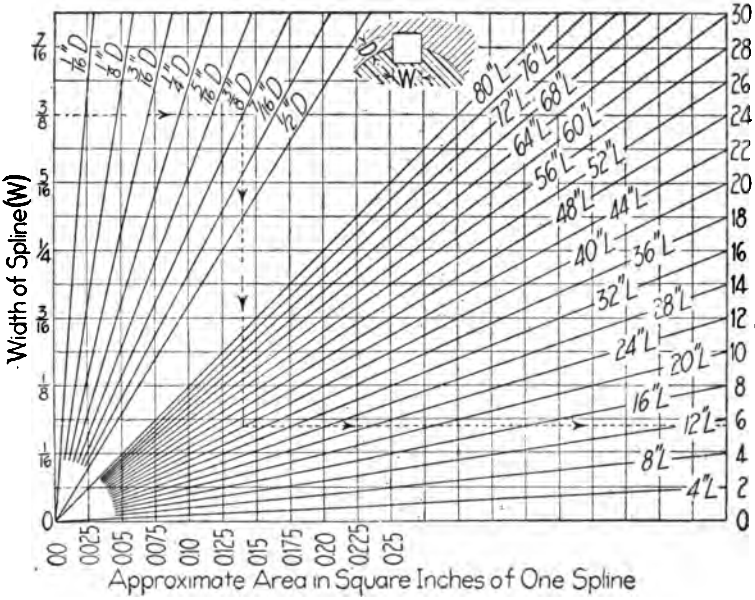


FIG. 109.—Chart to obtain sectional area and cubic inches for spline.

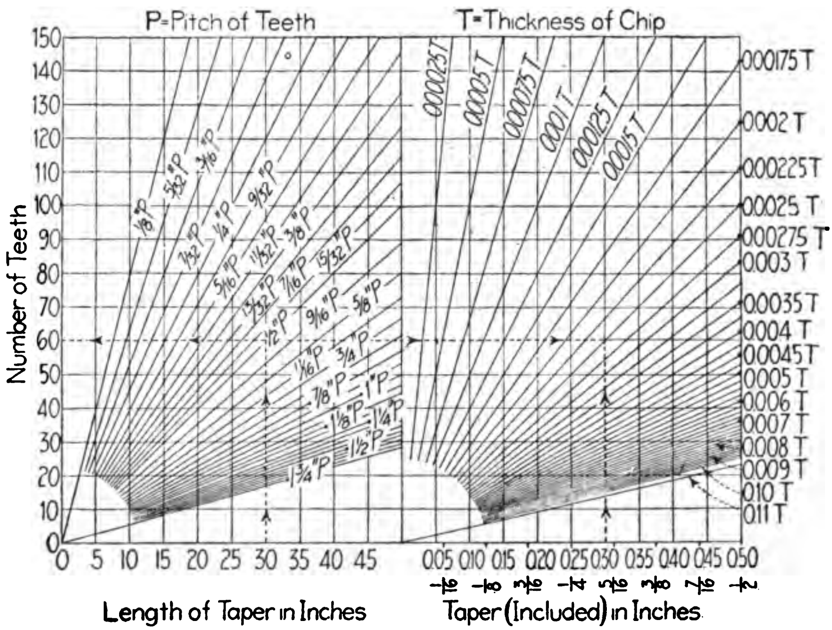


FIG. 110.—Relation of pitch, number of teeth, amount and length of taper and thickness of chip.

move depends greatly on the hardness or toughness of the metal to be broached. The size of a hole and its relation to the length also affects the amount the tooth should cut. Ordinarily, on medium-sized holes in mild steel, the teeth may increase 0.001, 0.002 or possibly 0.003 in. per tooth. On heavy pieces of brass or cast iron twice this is often safe. On large broaches for holes above 2 in. in diameter, where the broach will stand the pull, as much as 0.005 or 0.010 in. may be employed. One thing that should usually be kept in mind in laying out the depth of cut, and that is that if the cut of a tooth is too small it will have a tendency to drag and dull, thus increasing the power needed to pull the broach through and also endangering the finish and size of the hole. The length of a broach also depends greatly on the toughness of the metal and the nature of the hole. On the possible safe length of a broach depends the number to be employed to finish a given hole. On ordinary square holes the cutting capacity of a single broach is about twice its diameter. That is, if a broach is 1¼ in. square it has a capacity to cut 2½ in. long. When the work is of greater length, two or more broaches may be required to complete the operation, thus necessitating two or three pulls.

This, however, depends on the nature of the metal being broached, also the amount of radius which can be allowed on the corner of a square broach, as the more flat or radius the work is allowed on the corner, the easier it makes it for the broach, permitting same to cut a greater length.

Where a designer is in doubt about a broach being able to finish a hole at a single pass, it is usually better to make two and then when the finishing broach gets undersize, it can be ground and used for the first broach, and another made to finish with at a less cost than would a long new one. This is common practice where several broaches are employed on a hole, and the entire set can be kept in good shape by making a new finishing broach occasionally and eliminating the one that was used for the first cut, the others being accordingly moved down in the order of their use.

The clearance angle on the top of a tooth is usually around 2 or 3 deg. or less, some broaches having practically no clearance angle at all. In many cases the best way to provide clearance on the top of the teeth is to make a narrow land just back of the cutting edge, and parallel with the center line. After the broach is hardened and ground, this land is stoned with an oilstone so as to back it off slightly. Back of this land the clearance may be several degrees to the real slope of the back of the tooth.

The front faces of the teeth may have as much as 6 or 8 deg. of rake, in order to properly curl the chip, and the bottom of the tooth space should have as rounding a fillet as possible in order to strengthen the tooth and to assist in curling the chip. A curved tooth face is better than a straight rake, though harder to machine properly. The better results amply repay this on most work.

DIFFERENTIAL PITCH

While differential pitch of broach teeth is used considerably, no definite or uniform rule seems available. Some make a practice of increasing the normal pitch 0.005 in. for each space up to five, then dropping back and starting all over again. For instance: first space, 0.500 in.; second, 0.505 in.; third, 0.510 in.; fourth, 0.515 in.; fifth, 0.520 in.; sixth, 0.500 in.; seventh, 0.505 in. and so on. One well-known firm uses the following spacing: 0.595 in.; 0.605 in.; 0.610 in.; 0.615 in.; 0.625 in.; 0.595 in., etc. Other firms use as high as 1/64 in. or more increase in groups of three, still others use 0.002 or 0.003 in. increase in groups of five. As a matter of fact, the main object is to so differentiate the spacing as to do away with the teeth following in each others chatter marks, which can be done with almost any varied spacing within reason, and a few thousandths more or less is not apt to materially affect the result.

DESIGN OF KEYWAY BROACHES

In opening a series of articles in the *American Machinist* in April, 1917, Walter G. Groocock writes:

There are many points in broach design that are debatable, and this is particularly true of keyway broaches. They may be made in three different ways, and each of these ways has its own advantages and drawbacks. These broaches may be constructed as a simple series of blades that are drawn through the work, being held in position relative to the work by means of a locating center; or they may have similar rectangular blades each secured in its own stock or carrier; or they may be made with the cutting portion integral with the stock—that is, solid broaches.

The first kind is shown in Fig. 111 and is especially suitable for single-keyway jobs. The second system is much favored by some tool designers on account of the supposed cheapness of replacing the blades. The third system is at first sight the most expensive. This, however, is open to question. But suppose they are more expensive to make. In those plants where the closest of work is required—more particularly with regard to double-keyway work—such small added cost is more than offset by the accuracy of the product from the solid type of broach.

The one great drawback to the loose-blade broach is the fact that it is impossible to hold the blades sufficiently solid in their holder to prevent their springing to either one side or the other. As mentioned before, the type shown in the illustration is most suitable for single-keyway jobs, because the slight angle that may take place in pulling it through the work is not readily apparent even when a good gaging system is in vogue. Moreover, any angle that may exist can be readily accommodated by the single key and, therefore, is not so detrimental from the assembling point of view as a similar angle in the case of double-keyway jobs.

With this class of broach, the work is placed on the hardened work adapter *A*, which has a rectangular groove *B* milled through it lengthwise. The broaches should be a good sliding fit in this groove, but owing to the impossibility of keeping this fit sufficiently close, any variation in the material being broached or any difference in the sharpness of the corners of the broach teeth has a tendency to force the broach over to one side of the slot. The result of this crowding over is a more or less slight lean, or angle, of the finished keyway.

Two or more broaches are required to get a keyway out to the necessary depth; but when the number of pieces to be done will not warrant a complete set, a make-

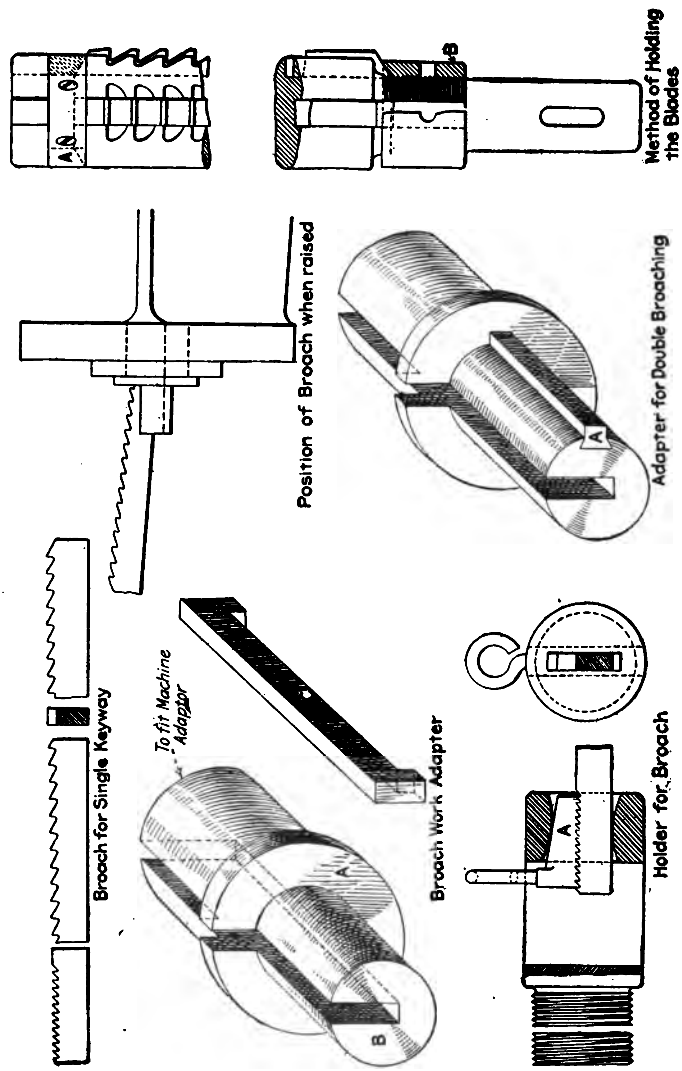


FIG. 111.—Various details in regard to keyway broaches and their use.

shift arrangement, as follows, will answer fairly well: Arrange the broach to take out half of the keyway at a pass, and for the second pass use a parallel gib key, as shown at *C*. Should the depth be such that a third pass is necessary, then a thicker gib will provide for this if the inclination of the broach teeth is adjusted to suit.

While this method may be used as a makeshift on a common grade of work, it should be pointed out that the more the broach is raised in the slot the greater will be the error in the result. Obviously, the less bearing surface the broach has in its adapter the greater will be the liability of its leaning over sidewise when at work. For this reason this system of using gibs should never be adopted when good results are required.

A good method of pulling broaches of this type is by means of the wedge, Fig. 111. The wedge is serrated on its under side, and the broach blade is serrated to correspond. The top side of the slot should be made rounded, as shown. The under side of the slot in the pull adapter should also be rounded.

The reason for this is as follows: In the tension-type broaching machine with this class of broach it is impossible to get everything in line, and a certain amount of float should be allowed. This is usually given in the slot and stem (of the round-stem type of broach). In the type under discussion, if the key and the bottom of the tension grip are flat, then when the tension comes on, the whole will be rigid. Consequently, the broach will be sprung, if any misalignment exists. A further reason for the rounding is that with some jobs the broach must be taken out, when run back, to put a fresh piece of work on the work adapter. The straight-type wedge requires a hammer to release it, whereas the curved wedge is easily released by raising the end of the broach, as shown.

Other Uses for Single-blade Broaches

The single-blade broach is often used on double-keyway jobs. Where the quantity of work to be done is small and accuracy is not of importance, it no doubt fills a want. But compared with either of the other two systems it is slow. One method used is as follows: The work is first broached out as if for a single keyway. It is then slipped on the work adapter, Fig. 111, and the operation repeated for the second keyway. The drawbacks of this method are, first, the work is handled twice for each broach; second, there is little chance of getting close results, because to get the work on and off the adapter without losing time the key *A* must be fairly free in the keyway already broached. Therefore, this allowance added to the small allowance in the broach slot has an effect on the accuracy of the finished work. This means that the assemblers have to ease the side of the keys to get the work together. Consequently, money saved in the first cost of broaches is spent in another section of the factory, quite apart from any question of interchangeability.

Another method of doing this class of work with a single broach is to have a dividing arrangement on the broaching machine whereby the work may be indexed for the second keyway. The drawbacks of this system are the first cost of the dividing arrangement, the slowness of the method—for not only must each broach be pulled through twice, but the work must be secured to the indexing fixture—and the uncertainty of the result, from reasons already stated. There is also another source of trouble through this method. Owing to the fact that, no matter how well a broach may be cutting, a certain amount of burr is thrown up, it is necessary to have the work adapter, or broach guide, rather slack in the bore of the work or it cannot be indexed without using considerable force. This means additional error in the result.

The second type to be discussed comprises broaches with blades inserted in a solid stock. This construction does not appear to give satisfaction in service.

Two methods that have been used are as follows: The broaches were designed to have the blade secured by means of screws, and each blade was in two parts, held by a screw at each end. The blades were let into slots in the stock and butted to the slot end. Although this set of broaches did much work, they were a constant source of trouble.

A Method of Holding the Blades

The other method, which is illustrated in Fig. 111, had some interesting points. It will be seen that the way in which the blades are held is the one adopted on reamers. The blades are secured in the center by a pad wedge, bearing on a ridge formed on the blades. This is not shown. The body for the broach has a groove cut in the end for the ring *A*. The two slots for the broach blades are milled from end to end. The ring *A* forms a stop for the blades, which are kept tight in position by the screwed ring *B*. For large broaches where this design can be applied, it has distinct advantages over the one already mentioned. From the tool maker's point of view, advantage is derived from the fact that the slots for containing the blades are milled through and can thus be ground true after hardening. This admits grinding the blades correct to width in their flat state and, incidentally, spare blades may be kept ready for insertion.

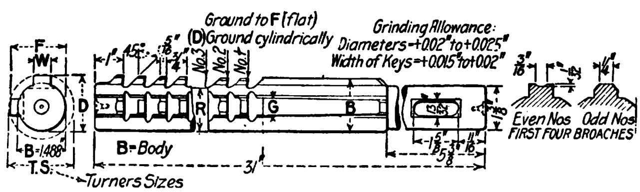


Fig. 112.—Double keyway broach with solid cutters.

Coming now to the solid type, Fig. 112, I have found that this style of keyway broach gives the best results because of the various reasons stated and for the further reason that I have never yet been able to keep the inserted blades tight in their position. Invariably they work loose and are a constant source of trouble. On the other hand, the only drawback to the solid broaches is that, because they are solid, they appear to be costly.

Experience has, however, demonstrated that, when accurate production is required, the solid type costs less to install and keep in order than do those with loose blades. In making the solid-type double-keyway broaches the stock is centered and turned, the size for the tooth portion being taken at the first and last tooth and turned parallel. Afterward a taper cut from one to the other completes the turning. Before the broaches are taken from the lathe, the positions of the teeth are lightly marked by rings made with a pointed tool. The next operation is milling away the bulk of the material, leaving 1/32 in. all round for the final milling. The teeth are cut in the shaping machine with a form tool made to the correct shape of the space. This tool is fed downward at an angle of 10 deg., thus giving the necessary front rake to the teeth. The operation of shaping the teeth is a very rapid one, as a boy can do this work on 100 teeth in 6 hr. After the key slot is milled in line with one of the rows of teeth, the whole broach is milled down to 0.015 to 0.025 in. over size. It is then ready for carbonizing.

Allowable Load per Tooth

The allowable load per tooth of a double-keyway broach can only be—with safety—the same as for a six- or eight-spline broach working on the same material. The figuring up, however, must be done differently. The reason for this is as follows: In double-keyway broaches with the keys at right angles to each other, when measurements are taken after the milling is done, the measurements are not

Table II.—Successive Diameters in Inches for Set of Solid, Double-keyway Broaches

No. of tooth	No. of broach					
	1	2	3	4	5	6
1	1.491	1.564	1.614	1.664	1.490	1.624
2	1.494	1.566	1.616	1.666	1.495	1.628
3	1.497	1.568	1.618	1.668	1.5	1.632
4	1.5	1.54	1.62	1.67	1.505	.1636
5	1.503	1.572	1.622	1.672	1.51	1.64
6	1.506	1.574	1.624	1.674	1.515	1.644
7	1.509	1.576	1.626	1.676	1.52	1.648
8	1.512	1.578	1.628	1.678	1.525	1.652
9	1.515	1.58	1.63	1.68	1.53	1.656
10	1.518	1.582	1.632	1.682	1.535	1.66
11	1.521	1.584	1.634	1.684	1.54	1.664
12	1.524	1.586	1.636	1.686	1.545	1.668
13	1.524	1.588	1.638	1.688	1.55	1.672
14	1.53	1.59	1.64	1.69	1.555	1.676
15	1.533	1.592	1.642	1.692	1.56	1.68
16	1.536	1.594	1.644	1.694	1.565	1.684
17	1.539	1.596	1.646	1.696	1.57	1.688
18	1.542	1.598	1.648	1.698	1.575	1.692
19	1.545	1.600	1.65	1.7	1.58	1.696
20	1.548	1.602	1.652	1.702	1.585	1.7
21	1.551	1.604	1.654	1.704	1.59	1.704
22	1.554	1.606	1.656	1.706	1.595	1.708
23	1.557	1.608	1.658	1.708	1.6	1.712
24	1.56	1.61	1.66	1.71	1.605	1.714
25	1.563	1.612	1.662	1.712	1.61	1.714
26	1.563	1.612	1.662	1.714	1.615	1.714
27	1.563	1.612	1.662	1.714	1.62	1.714
28	1.563	1.612	1.662	1.714	1.62	1.714
T. S.						
1st tooth	1.52	1.675	1.745	1.865	1.52	1.75
26 Tooth	1.675	1.745	1.865	1.965	1.75	1.96
B	1.488	1.55	1.59	1.64	1.7*	1.59
C	0	0.404	0.403	0.402	0.4	0.439
R	1¼ in.	1⁹⁄₃₂ in.	1⁵⁄₁₆ in.	1⁵⁄₁₆ in.	1⁵⁄₁₆ in.	1⅜ in.
W	0.406	0.405	0.404	0.403	0.439	0.439
F	.....	.....	.....	1.693	.....	1.693
*Turn	1.93					

made the full diameter, but only across the body and one tooth. This, of course, applies also to spline broaches with an odd number of splines. Therefore, the rise per tooth to be allowed on the table showing sizes for a six-spline broach would be double the rise per tooth given on the table for a double-keyway broach having the same load per tooth.

A standard sheet for this type of broach is shown in the table, made for broaches with 28 as the maximum number of teeth. This covers the range of length that can be made on an ordinary-size miller. Two points in Fig. 112 need special mention. Keyways, when finished, have square bottoms, while the dimension *D* is finished as a radius. This means that the last few teeth have to be ground flat on the surface grinder. The dimension *F* covers this point and represents the size of the hole plus the depth of the keyway in the work. Another point is the dimension *G*. This may be expressed either as shown or as the depth of the chip space. As shown, the chip space would vary in depth. When the spaces are shaped in with a form tool, *R* is best expressed as the depth to be cut. To avoid repetition, the load per tooth and the method of applying the load for keyway broaches will be discussed under spline broaches, from which they do not differ in any essential detail.

The sizes that were used for a very successful set of broaches are given in Table II. These broaches have done good work on deep keyways in gears made from tough steels used in the automobile trade. The lengths of the holes varied from 3 to 4 in.

DESIGN OF ROUND BROACHES

For years reamers have been used to size holes—say in the drilling machine—and those who have had most experience with reamers must know what an uncertain tool a reamer is, yet the round broach for sizing work is comparatively neglected. While the broach will never entirely displace the reamer, there are in every plant innumerable pieces of work that are particularly suitable for broaching purposes, such as levers, single-hole brackets and the like. Take, for instance, levers; these can be rough-drilled 1/32 in. undersize and then broached to size, thus giving a cheaper and better job.

Broaching is cheap, because a round broach costs little more to make than a solid reamer of high-speed steel; and yet the broach will produce more holes within predetermined limits than will a solid reamer. This means that the tool cost per piece is relatively low and much in favor of the broach; and while the actual time of sizing the hole does not differ much for small holes, for holes over 1 in. in diameter the broach has a decided advantage.

A type of standard drawing for making round broaches is shown in Fig. 113. The table gives dimension details of a few standard sizes the proportions of which have given satisfaction. It is best to leave the table blank on the tracing of the broaches, filling the sizes in on a blue-print as different sizes are put in hand. By so doing any change that experience suggests as desirable may be embodied in future broaches without erasures on the tracing.

TABLE III.—DETAILS OF STANDARD SIZES OF ROUND BROACHES, IN INCHES

Nominal size	*A*	*B*	*C*	*D*	*E*	*W*	*G*	*J*	*L*	*P*	*N*	*R*	*r*	Remarks
3/4	0.751	0.735	.....	17/32	1 1/4	7/32	4	3/32	25	3/8	8	1/8	7/32	Five notches
7/8	0.876	0.86	.....	9/16	1 1/4	7/32	4	1/8	25	3/8	8	1/8	1/16	Six notches
1	1.001	0.984	.....	5/8	1 1/4	1/4	4	1/8	25	3/8	8	1/8	1/16	Six notches
1 1/8	1.126	1.1	1	3/4	1 1/4	1/4	4	1/8	25	3/8	8	1/8	1/16	Six notches
1 1/4	1.251	1.215	1 1/8	7/8	1 1/4	11/32	4	1/8	25	3/8	8	1/8	1/16	Six notches
1 3/8	1.376	1.34	1 1/4	1	1 5/16	3/32	4	1/8	25	3/8	8	1/8	1/16	Six notches
1 1/2	1.501	1.47	1 3/8	1 1/8	1 5/16	13/32	4	1/8	25	3/8	8	1/8	1/16	Eight notches
1 5/8	1.6265	1.59	1 3/8	1 1/4	1 5/16	13/32	4	1/8	25	1/2	6	3/16	1/16	Eight notches
1 3/4	1.7515	1.72	1 5/8	1 5/16	1 5/8	7/16	4	1/8	25	1/2	6	3/16	3/32	Eight notches
1 7/8	1.8765	1.84	1 5/8	1 7/16	1 5/8	7/16	4	1/8	25	1/2	6	3/16	3/32	Ten notches
2	2.0015	1.96	1 5/8	1 9/16	1 5/8	......	4	1/8	25	1/2	6	3/16	3/32	Ten notches

Changes that may be found advisable are pitch of teeth, spacing of notches, or total load. For instance, it will be obvious that the pitch of the broach teeth must be less than the width of the work, or the work will drop into the teeth. Consequently, for a thin job like a washer the pitch may have to be finer, failing some special means of holding the work. On the other hand, for a very long hole the pitch may have to be coarser, to lessen the total load on the broach or to provide more chip space. The notching may have to vary to suit a given material. Usually, however, for sizing holes up to 1 1/2 in. in diameter 3/8 pitch is satisfactory, and 1/2-in. pitch gives good results up to 1 7/8 diameter. For broaches larger than this the pitch should be wider; and the depth of the spaces may be materially increased, thus lightening the broach, which makes for easier handling.

While there is no limit to the size of round broach that may be used—except the power of the machine to pull it—it should be stated here that all round broaches have a tendency to work downward, owing to their unsupported weight. Naturally, the effect of this would be greater with the heavier broaches.

For this reason—among others—it is desirable that broaching machines should be built with an outboard support, or extension, which should be integral with the main casting of the machine. A sliding block on this extension could then be used to keep the broaches in line. Where there is no support for the broach other than the pull adapter, the work adapter must be renewed frequently so that the broach cannot sag too far out of line. These adapter bushings may be bored out to the next larger size and consequently may be used again.

Apart from ordinary standard broaches there are many cases where special round broaches are of advantage. Malleable-iron castings may be broached direct from a cored hole when the location of the hole is not important. For this work, round broaches that have lost their size may be ground to take out the necessary amount of material. Such a broach would of course be followed by a standard broach to size the hole. When the cored hole is not more than $\frac{1}{16}$ in. below the required size, a reground broach may be used without rehardening, but generally, owing to irregularities in the cored hole, the reduction of the broach will necessitate rehardening.

Large round broaches made from case-hardened steel, which have lost their size, may be brought back to standard by rolling up the last few of the

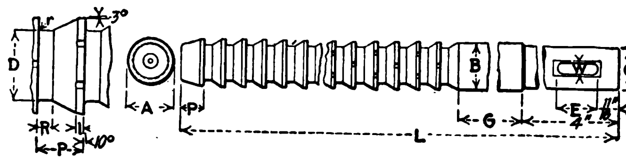


FIG. 113.—Standard drawing for round broaches.

teeth, say six, and then regrinding these to do the sizing. To do this a small roll is mounted on the end of a pin 1 in. square. This holder is mounted on the lathe rest at an angle, the roll is applied to the front of the desired teeth, and pressure is applied while the broach is slowly revolving in the

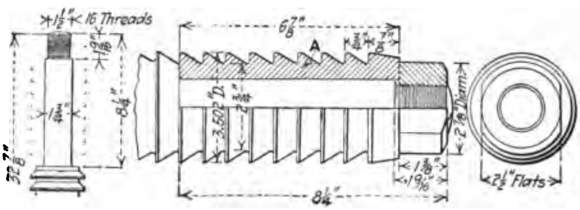


FIG. 114.—Broach with detachable end.

lathe. If the tooth faces have been frequently reground to sharpen them, it is a simple matter to increase the diameter of a tooth to the extent of 0.01 in. If, however, the case at this point is still deep, it takes considerably more effort to get an increase of, say, 0.005 in. in diameter.

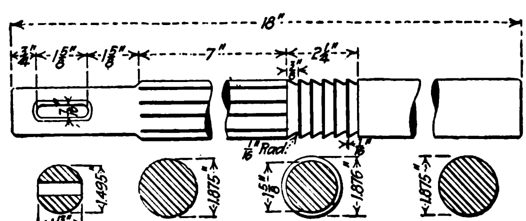


FIG. 115.—Broach for removing burrs from splined holes.

Very large round broaches may be made with a detachable end, like the one shown in Fig. 114, the detachable portion being secured in position by a nut. In this type of broach it is advisable, to get the best results, to work along the following lines: When the broach is first made, only about two of the teeth on the auxiliary broach do any work, the remainder being idle teeth. When the broach has lost its size, beyond the rolling-up stage, the detachable portion is taken off and a new one taken from stock and secured in position. The detachable ends should be kept in stock, hardened, ground in the hole and on the end, but not on the teeth. After the broach is again built up, the new portion should be ground to size and the remainder of the broach reground. To do this the taper, or slope, of the broach is slightly changed, which allows all the teeth to be resharpened on their diameter, the replaced end having fewer idle teeth than the original end, according to the condition of the broach teeth that have not been changed. This design of detachable ends is only applicable to the larger type of round broach.

Another type of round broach that has been found useful for taking off burrs from splined holes is shown in Fig. 115. This needs little description. Only a few teeth are cut about the center of the broach, the front part of which is grooved to clear the burrs. The plain back portion acts simply as a guide to keep the work in alignment.

Owing to the fact that there is little work for such broaches to do—that is, they only have to remove burrs—they retain their size for quite long periods.

DESIGN OF SQUARE BROACHES

As with other types of broaches, when designing square broaches one is confronted with several different methods of arranging them. In the long broaches it is customary to have the width of the flats practically the finished size from end to end. There is, however, one very good reason why this system is not particularly sound practice; and that is, when the broach loses its size, and it must do so sooner or later, then one has either to put in another short broach just to size the hole or make a complete long one and scrap the one that is under size. Further, if the broaches are designed to pull out the hole to its finished size across the flats from the start, it will be found invariably that there are several nasty scores or marks in each hole. While these drags may not be sufficiently bad to scrap the work, they certainly do not add to its appearance or utility.

Obviously, the best holes, from a wearing point of view, are those that have the smoothest surfaces. This being so, then the endeavor must be to secure this desirable feature. The cleanest holes that can be produced by broaching are obtained by making the set of broaches in two parts, one part of the set pulling the holes out—for square holes—to within, say, 0.005 in. of size across flats for small squares and within 0.01 in. for large squares; the final broach in this system then just takes a scrape all over the hole and leaves it in good condition. Aside from excellent finish by this method of arranging the broaches the useful life of the set is very much prolonged because the finishing broach, having so little to do, will produce many more holes within predetermined limits than it would if it had part of the roughing out to do.

There are other good reasons why the finishing of the hole should be done by the last broach in the set. The time will come when the hole produced will not be to gage. Although a good sharpening across the face of the teeth and a second pull through of the finisher will temporarily overcome this difficulty, another broach must be used to finish with; and it must of necessity take a shave around the flats. Aside from the possibility of replacement by using the last broach to size the flats, one can considerably lessen the cost of a set of square broaches.

Each roughing broach may be made to just clear the hole left by the previous broach, and in a general way they may vary, say, 0.002 in. across the flats below the size that it is intended to make them. This means, of course, that the finish grinding of the flats can be considerably hastened, because less care will be required with such a limit. Consequently, by adopting this system only one broach in the set needs particular care in finishing. Those who know the difference between attempting to work to size and working to a limit of 0.002 in. will appreciate the importance of this point. The set of broaches should be so designed that the finisher has nothing, or at most only a few thousandths of an inch, to take out of the corners, and this work should be spread over the first few teeth, say 0.001 in. per tooth, thus insuring clean finish to the corners.

By giving the finishing broach very little to do on its corners when new, one is enabled to regrind the roughers when required; and whatever reduction takes place on their corners owing to grinding, it can be met by reducing the first few teeth corners of the final broach. Thus, it is assured maximum life, while at the same time the broaches are kept in such condition that they will give good clean results on the very toughest material. To do this they must be kept sharp.

Besides just touching the corners of the hole the last broach of the set must take a slight scraping cut along the whole of the flats of the square hole; and to do this, every tooth must be carefully backed off to a cutting edge. The roughing broaches should not be relieved on the flats, but should have a ground land, approximately as shown at *A*, Fig. 116. The curved front is due to the undercutting of the face of the teeth, and it will be referred to again.

In designing square broaches there is no infallible rule by which success may be achieved, except the rule that is common to all design—that is, to base the proportions on the proportions of some successful set, embodying any new data that experience points to as being either necessary or desirable.

The best way undoubtedly is to draw two teeth of each broach very carefully as to size, after one has figured out roughly the load per tooth and the number of broaches to a set. Two longitudinal views should be drawn, one taken across the flats and one across the corners. In this way one is

TABLE IV.—DATA FOR SQUARE BROACHES

Nominal size of broach		Original diameter of hole, in.	No. of broaches per set	No. of teeth per broach	Pitch of teeth, in.	Total length of broach, in	Effective teeth, load per tooth and root diameter																	
							No. 1 broach			No. 2 broach			No. 3 broach			No. 4 broach			No. 5 broach			No. 6 broach		
Flats, in.	Corners, in.						Effective teeth	Load per tooth in 0.001 in.	Root diameter, in.	Effective teeth	Load per tooth in 0.001 in.	Root diameter, in.	Effective teeth	Load per tooth in 0.001 in.	Root diameter, in.	Effective teeth	Load per tooth in 0.001 in.	Root diameter, in.	Effective teeth	Load per tooth in 0.001 in.	Root diameter, in.	Effective teeth	Load per tooth in 0.001 in.	Root diameter, in.
5/8	7/8	5/8	3	36	7/16	24 1/2	32	3	7/16	32	4	1/2	13	2	1/2									
3/4	1 9/32	3/4	4	36	1/2	26 1/2	34	2	9/16	34	3	9/16	33	3	5/8	12	1	5/8						
1	1 21/32	1	4	30	5/8	29	27	3	3/4	27	3	51/64	27	3	53/64	20	2	55/64						
1 1/4	1 23/32	1 5/16	4	34	5/8	31 1/2	30	3	1	30	5	1 1/32	30	4	1 1/16	9	2	1 1/16						
1 3/8	1 9/32	1 3/8	6	24	3/4	28 1/2	22	2	1	22	3	1 1/16	22	4	1 1/8	22	4	1 1/8	22	4	1 1/8	11	3	1 1/8
1 3/4	2 9/32	1 3/4	6	24	7/8	31 1/2	22	4	1 1/4	22	5	1 5/16	22	5	1 3/8	22	5	1 3/8	22	4	1 3/8	15	3	1 3/8
2 1/8	2 17/32	2 1/8	5	24	7/8	31 1/2	22	6	1 1/2	22	4	1 1/2	22	4	1 5/8	22	4	1 5/8	6	2	1 5/8			
2 3/8	3 3/16	2 7/16	6	24	7/8	31 1/2	22	5	1 7/8	22	7	2	22	5	2 1/16	22	4	2 1/8	19	4	2 1/8	7	1	2 1/8
2 15/16	4	3	6	24	7/8	31 1/2	22	15	2 1/8	22	10	2 3/16	22	8	2 1/4	22	6	2 1/4	22	6	2 1/4	9	2	2 1/4

All for use on high-class alloy steels. Work varies from 3 to 5 in. in length.

enabled to see clearly whether there is enough chip room and whether the tooth looks strong enough in the corner view. The root diameter should be checked to see that it is a stronger section than one taken across the pulling slot of the broach. The difference between a corner view and a view of the flats is clearly shown in the illustration.

These broaches were for use on steel forgings of from 3 to 4 in. through the hole. The data for the full square are given at the bottom of the data sheet, and it will be seen that the set consists of six broaches. The first and second broaches appear to have an abnormal load, but in reality their load is small. The articles to be broached, one of which is shown in Fig. 117, are stamped with a square hole; and naturally the forged hole has considerable draft. After it is bored to 3 in. in diameter, the hole looks as it appears at *A*, the line *B* representing the square hole on the edge of the forging and the line *C* being the center of the piece. The portion shown hatched at *D* is the material to be broached out at the corners. It will be seen that the first and second broach—the first in particular—act on only a short portion of the hole, hence the apparently heavy load.

This set of broaches proved particularly clean in their cutting, and from the easy way in which they did their work it is evident that they might have been loaded still more. But to have put sufficient work on the leading broaches to enable the cutting out of the fifth broach would, without a doubt, have considerably shortened the life of the set. It is a great temptation to the designer, when a set of broaches have been very successful, to increase the load per tooth on the next similar set that he may design; but it is always well to remember that every year the material that we have to broach is getting more and more difficult to deal with. Consequently, the proposition to be considered is not so much "how many pieces per hour" as it is "the cost per piece to be broached."

A set of four broaches may be designed to do a job and work satisfactorily until they have done, say, 1000 pieces. Then they may fall down badly and have to be replaced. Suppose the cost of such a set of broaches is $100. The introduction of another broach into this set would increase the cost of the set by 25 per cent., but it would probably mean that such a set would be in good order after doing 5000 holes. If, now, the labor cost for broaching be considered, in the case of the four-broach set it would be only 20 per cent. less than that for the five-broach set. One can see at once that the small saving in labor cost is very much overbalanced by lower broach cost per piece of the five-broach set. In this, then, as in all good shop practice, the unit cost of production must be considered and not the labor charge alone.

Proper Length of Cutting Edge

There is one point in connection with the design of large square broaches that should be mentioned; that is, the length of cutting edge in the first two broaches is such that it is preferable to notch the cutting edges, so as to break up the chips. This notching should be carried out all along the first broach and part of the way along the second. The notching should of course be

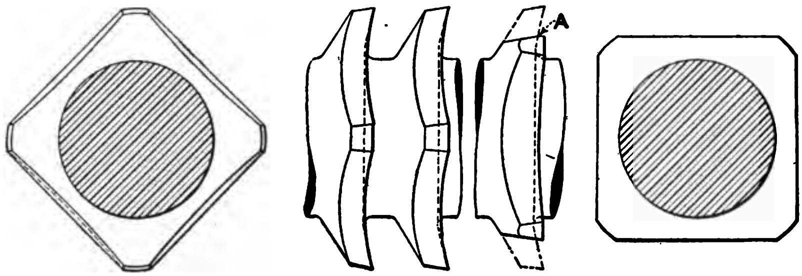


FIG. 116.—View to show land on teeth.

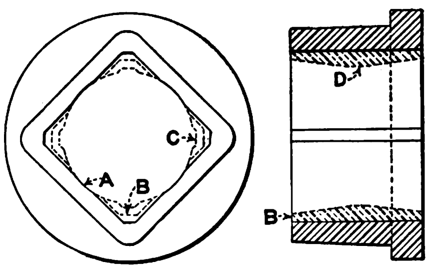


FIG. 117.—Article to be broached.

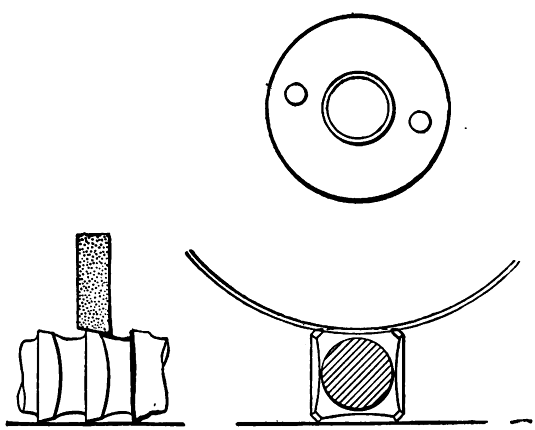


FIG. 118.—Grinding broach with edge of wheel.

staggered, so that, as in milling, one tooth takes out what the previous tooth leaves.

An interesting contrast to the large set of square broaches just discussed is provided by considering the second set of data given in the accompanying table. This set of four broaches had to pull out a ¾-in. square hole up to 3 in. long and almost to a sharp corner. The material was a high-grade alloy steel used on automobile gears, and on this material the broaches worked well. This set gave excellent results, and they undoubtedly have sufficient chip room to work in holes up to 4 in. long. They were designed to work from a ¾-in. rough bored hole.

Grinding the Flats on a Broach

The grinding of the flats of square broaches may be accomplished in a variety of ways; but if a Bath spline grinder is available, then with a cup wheel square broaches are a simple proposition. The roughing broaches should be ground parallel the whole length, and afterward the table should be tilted so as to taper the guide portion slightly. When grinding the finishing broach, the finishing end—about six teeth—should be ground parallel and about 0.001 in. over the size of the hole required. Afterward the guide and the remainder of the teeth should be ground taper, the guide being of such size as freely to enter the hole made by the roughing broaches. After this all the teeth along the taper portion of the finisher must be relieved to a cutting edge.

The method adopted to relieve these teeth will of course depend on what machine is available; but as most tool-rooms now have a small surface grinder, I will assume that small Brown & Sharpe machines can be used and will discuss two ways of relieving the teeth, which have been found to give good results in minimum time. These two methods are outlined in Figs. 118 and 119.

In the first case the wheel is trued up to a bevel of 3 deg. The work is laid across the table of the surface grinder and is held at right angles to the wheel—that is, parallel to the wheel axis—by means of two parallels clamped to the machine table. The wheel is brought down on each tooth in turn, and the grinder table is moved by the handwheel, thus traversing the broach under the wheel. By this means each tooth is in turn brought up to a cutting edge. When working this way the broach passes through the standards of the machine and also between the belt. With large-sized broaches there is likely to be interference by the belt. To protect it from accidentally catching on the corners of the broach teeth and thus getting cut, it is advisable to bend a U-shaped piece of sheet steel and lay it across the broach where the belt may foul.

Method To Be Used for Long Broaches

For square broaches over 2 in. this method cannot be used, because the belt rubs badly before the wheel is across the tooth; that is, the travel by this method—on a small Brown & Sharpe—is limited. In such cases we may fall back on the method outlined in Fig. 119. More skill is required in the operator, but the process is perfectly safe for any tool maker who has acquired the "feel" of the machine. The broach to be relieved is laid longitudinally on the table, being held at right angles to the wheel axis by parallels clamped to the table. The wheel is brought down between two teeth to a predetermined depth, which need not be varied, and the table is moved longitudinally so that the wheel just touches the tooth to be relieved. The broach is then traversed by hand underneath the wheel by means of the cross-traverse handwheel; and the platen of the machine, carrying the broach, is moved just far enough to allow the grinding wheel to relieve the tooth to a cutting edge.

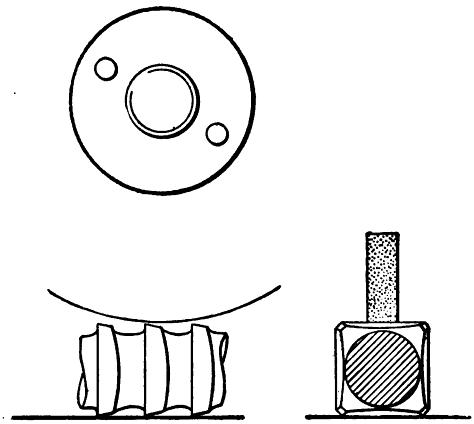


FIG. 119.—Grinding large sizes of broaches.

This operation, which takes only a fraction of the time required to describe it, is then repeated on all the teeth. The teeth left parallel at the end of the broach should not be brought up to a cutting edge, but should have about 1/32-in. land. The only drawback to this method is, of course, the fact that a curved relief is obtained, which is greater at the cutting edge than it need be. However, by using a 7-in. diameter wheel the hollowness of the relief is not very pronounced.

There is another point about the grinding of the finishing broach that must be mentioned here, because it materially affects the design. To get good clean cutting at the corners of square broaches it is advisable to undercut the face of the teeth to the extent of about 10 deg. If this is carried all the way along the finishing broach, one will have difficulty in getting a square hole with perfectly flat sides, because as mentioned before, the undercutting of the teeth gives a curved outline to the cutting edge. Consequently, the cutting edge is relieved by moving a grinding wheel across it in a straight line. It will be found that the center of the flat comes to a cutting edge before the outside. This means that if the whole of the flat be relieved, the broach will be lower in the middle than on the outside of the flats, and naturally the hole produced will be larger measured at the sides than it would if measured in the center. This result is shown exaggerated, in Fig. 120, by the curved lines. The following method gets over this difficulty.

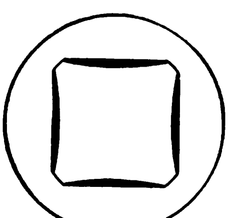


FIG. 120.—Diagram of error due to undercutting of teeth.

As the finishing broach will never be called upon to cut on the corners, except the first few teeth, the broach need not be undercut the whole of its length. Differential undercutting may be used, as follows: First four teeth, 10 deg.; next four teeth, 7 deg.; and four following teeth, 5 deg. undercut. All the remaining teeth should have flat faces. The result of this is that, when all these teeth are relieved to a cutting edge by a straight-line relief, those that are undercut will cut on the flats near the corners first, while those with less undercut will take more from the center. The teeth with flat faces will take a scrape right across and leave a square hole with a flat side.

The standard drawing recommended for square broaches is given in Fig. 121. Blank dimension sheets should be prepared, which may easily be filled out with the dimensions necessary for any set of broaches. The drawing can also be used for hexagonal broaches by changing the end view. This may be done in the way suggested for spline broaches—by means of an auxiliary print showing the end views of the various shapes.

All that was said with reference to the data sheet shown in a previous article applies with equal force to the data for square broaches, in Table

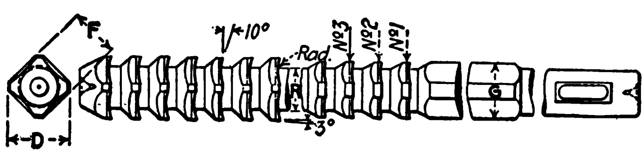


FIG. 121.—Standard drawing for square broaches.

IV. This sheet gives the essential particulars of a few successful sets of square broaches and needs no further comment.

* * * * * * * * * *

In estimating the power required to pull a broach through a cored hole, 4⅛ in. square, and 4 in. long, in a steel casting, in which the cored hole was broached to a 4¼-in. round-cornered hole, J. N. Lapointe estimated the power needed to be about 16,000 or 17,000 lb.

BROWN & SHARPE BROACHING PRACTICE

Besides doing broaching on various parts for machines built by them, the Brown & Sharpe Mfg. Co., Providence, R. I., does considerable work of this kind for automobile or other concerns. A few examples of work done in its shops are shown in Fig. 122 and include spur and bevel gears, and cranks and collars in which keyways or square and hexagon holes are broached.

Some of the gears in which round-cornered, square holes are broached, are for automobile transmissions, and consequently, are of particularly tough steel, so that for the 1¼ size, seven broaches are necessary to produce accurate results without tearing the metal or overtaxing the broaches. The set of broaches used for this size of hole is shown in Fig. 123. From this it

FIG. 122.—Example of broached work.

FIG. 123.—Set of broaches for round-cornered square holes.

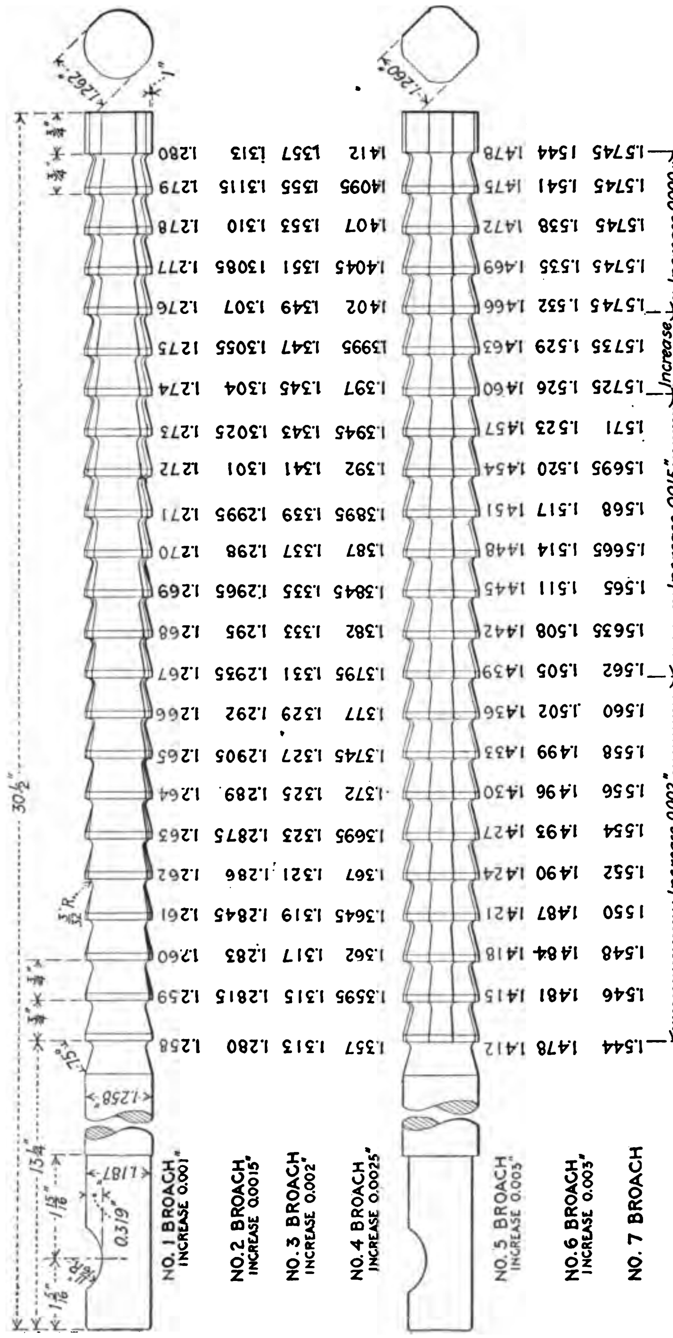


FIG. 124.—Details of a set of broaches for round-cornered, 1¼-in. square holes.

will be seen that none is of the excessively long type often seen, but now less used than formerly. The semicircular recesses in the shanks, in which the eccentric clamp of the holder fits, are also plainly shown. Details of the various dimensions and tooth sizes of the 1¼-in. set of broaches are given in Fig. 124.

TO SAVE TIME IN BROACHING OUT SQUARE HOLES

The fit of gears on a square shaft depends almost entirely on the flat surfaces at or near the corners, and very little on the center portion of the flat surface. With this in mind, drill the round hole in the gear slightly larger than the diameter across the flats of the squared shaft, as shown in Fig. 125.

Taking a 1¼-in. square shaft and boring the hole 1/16 in. larger or 1 5/16 in. in diameter, we see in the illustration exactly what this means. The amount of metal to be cut out is materially reduced, the portion *A* to *B* not being touched by the broach in any way. Yet the remaining surface in

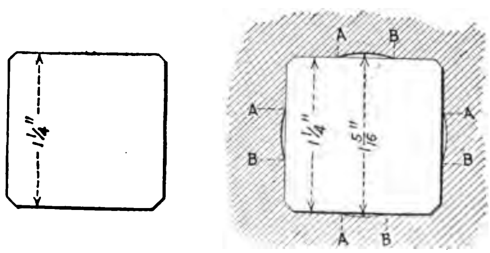


FIG. 125.—Broaching saved by boring hole larger.

the corners is ample to carry all the load of the gears at work, and the clearance *A* to *B* allows the best of lubrication for the gear and shaft.

There is also another point. The center relief as shown, gives considerable added chip space as well as reduces the amount of chip, thus allowing a heavier chip per tooth. This reduces the length of the broach or allows a longer hole (such as two gears at once) to be broached with the same length of broach.

DIMENSIONS FOR HEXAGON, SIX-SPLINE AND BUTTON BROACHES

The fact that in order to stand the terrific strain, gears used in modern automobiles must be made of the toughest steel that it is possible to use, renders the machining processes interesting from a number of viewpoints. Especially is this true of the broaching proposition.

The transmission gears used in the automobiles made by one of the big companies, are made from chrome-nickel steel, and the broaches used for working out hexagon and six-spline holes in these gears will be described in detail.

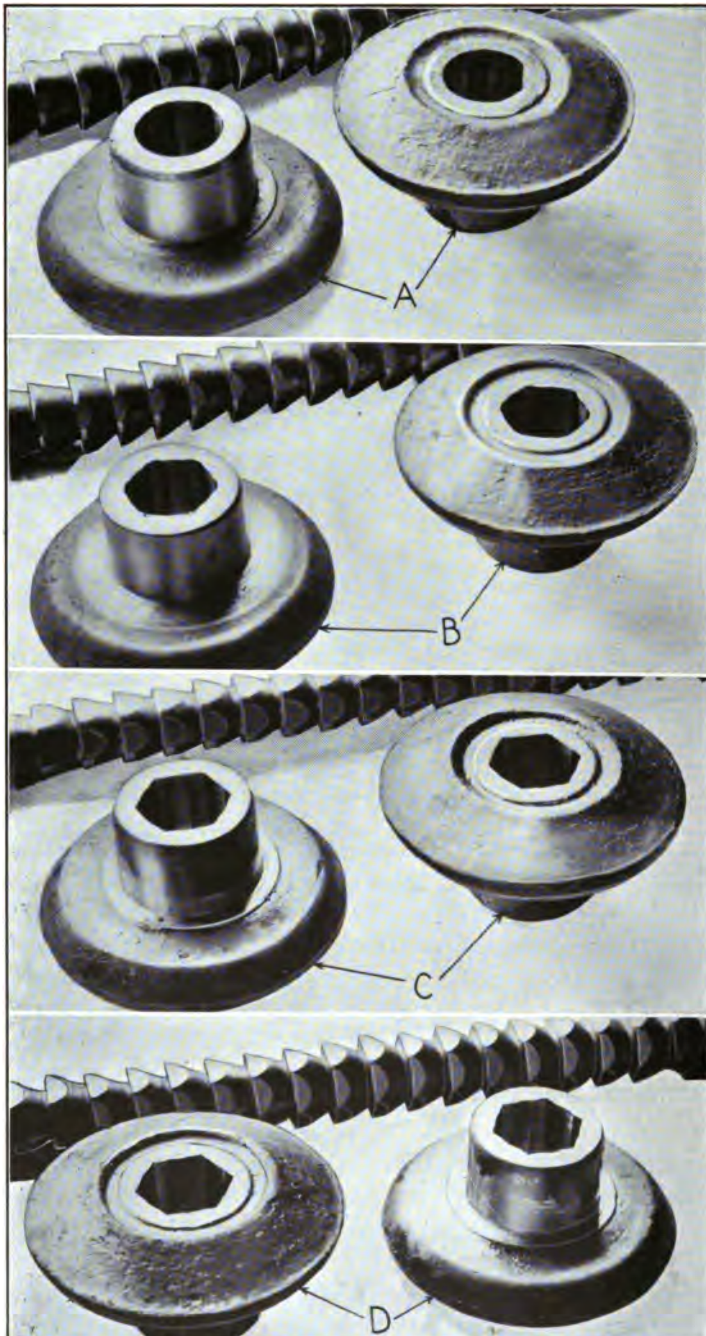


FIG. 126.—Steps in the broaching of a hexagon hole.

Three broaches are used to broach out the hexagon holes in the bevel gears shown in Fig. 126. The separate operations are represented in order

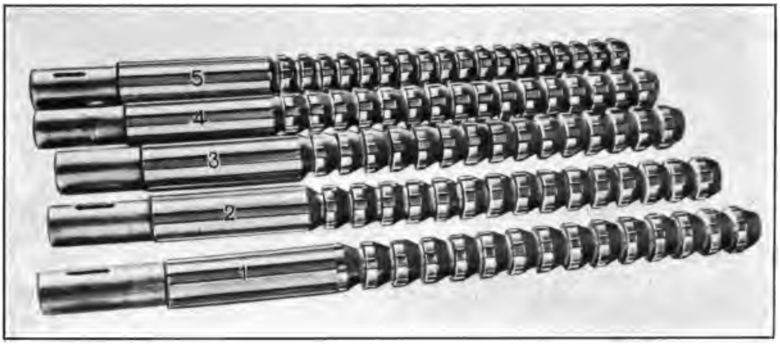


Fig. 127.—Set of five broaches for a six-spline hole.

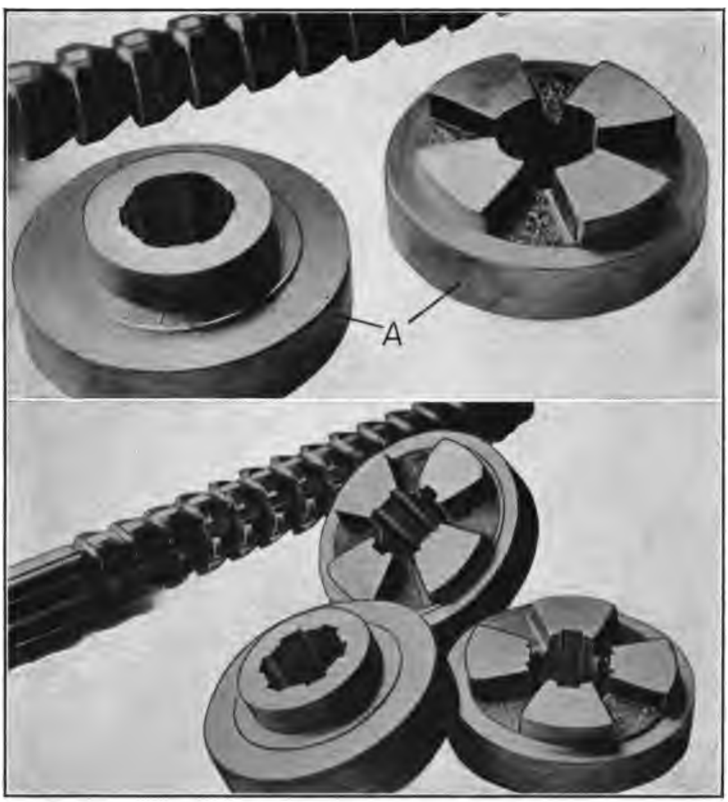
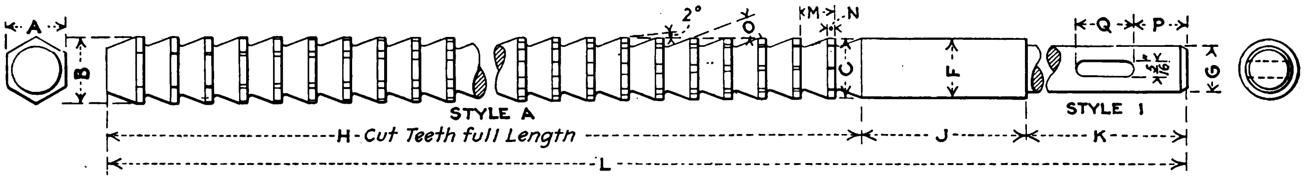


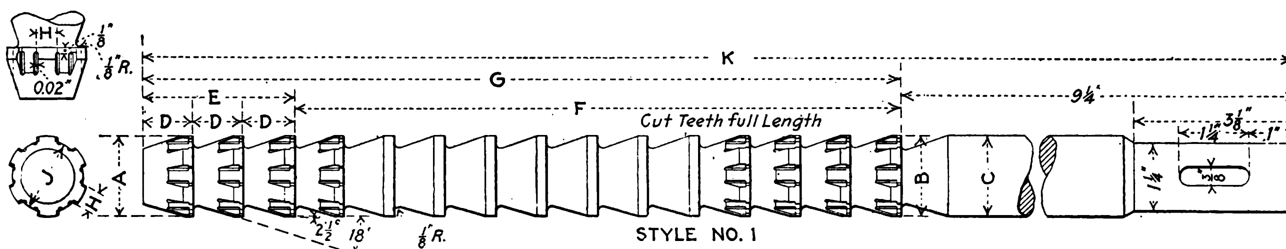
Fig. 128.—First and last steps in broaching a six-spline hole.

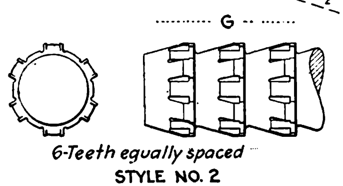
by the gears *A*, *B*, *C* and *D*, two gears being shown for each operation, in order to show both ends of the hub.



BROACH	STYLE OF BROACH	STYLE OF SHANK	A	B	C	F	G	H	J	K	L	M	N	O	P	Q	REMARKS
1st Broach	A	1	1.376"	1.457"	1.406"	1.406"	1 3/16"	27"			33 7/8"	3/4"	3/16"	20°	1 1/4"	1"	
2nd Broach	"	"	"	1.504"	1.453"	"	"	"			"	"	"	"	"	"	
3rd Broach	"	"	"	1.550"	1.499"	"	"	"			"	"	"	"	"	"	
4th Broach	"	"	"	1.590"	1.546"	"	"	"			"	"	"	"	"	"	Last 4 Teeth Straight

FIG. 129.—Dimensions of hexagon broaches.





BROACH	STYLE	A	B	C	D	E STR.	F TAPER	G TAPER	H	J	K
First	1	1.613"	1.555"	1.553"	1"			15"	.04375"	1.555"	.24 1/4"
Second	1	1.664"	1.606"	1.553"	1"			15"	"	"	"
Third	1	1.718"	1.657"	"	1"			"	"	"	"
Fourth	1	1.754"	1.708"	"	1"	3"	12"		"	"	"
Fifth	2	1.760"	1.738"	"	1"	3"	12"	"	"	"	"

FIG. 130.—Dimensions of six-spline broaches.

The proportions of the broaches used are given in Fig. 129, and it will be observed from this that the first tooth of the first broach is the same size as the shank, but that several thousandths are allowed for the entering teeth of the following broaches. This is done to allow for the wearing or grinding down of the final teeth of the preceding broach. The last four teeth of the finishing broach are left the same size to prolong the life of its accuracy. The length of these hubs varies from 1¾ to 3 in. and the time for each broach is 1 min. 20 sec. and 25 sec. return stroke.

On the gear blanks shown in Fig. 128, five broaches are used. The first operation is illustrated at *A*. The fifth operation is shown just below, and by carefully examining the splines, it will be noted that small grooves are cut in the corners, obviating the necessity of cutting to a sharp corner in order to make the gear slide well on the feathered shaft, and incidentally greatly prolonging the life and usefulness of the finishing broach, as it is difficult to keep sharp corners on the teeth of a broach of this type in such tough metal. The length of these hubs varies from 1¾ to 3 in. and the time for each broach is 32 sec. with 18 sec. return, or an actual cutting time for the 5 broaches of 4 min. 10 sec.

The complete set of broaches is shown in Fig. 127, and the exact proportions are given in Fig. 130. The practice here, it will be observed, is to make the broaches rather short, the tooth length for the hexagon broaches being 27 in. and for the six-spline only 15 in. This not only makes them easier to make, harden and handle, but quicker work can be done with them, as five of these broaches can be run through the work in less time than three long ones.

Right here is a good place to bring out the fact that in designing all broaches, it should be borne in mind not to have the teeth so closely spaced that too many of them will be in the work at the same time. If there are, too much power will be required to draw the broach through, resulting in slower and more costly production and danger of stalling the machine or pulling the broach in two. Closely spaced teeth also increase the danger of clogging with chips. These are points often overlooked by those designing broaches for special work.

Machining the Broaches

The practice at the Alco shop is to center bars of steel of the proper size, then turn and cut the teeth in a lathe, the larger sizes not even needing a steady-rest, but the small slender broaches being either supported in a steady-rest or by a follower.

A very important point in making broaches for hard steel, like the gears shown, is to undercut the teeth about 2 deg. and form a smooth fillet at the root of the teeth, so as to give the chip a nice curl and not merely scrape the metal off. As a general rule, about 0.002 in. is allowed as the increase in size per tooth. This allows the tooth to "bite" properly, even when slightly dull.

After the teeth are cut, they are shaped in a miller, using a dividing head and a tail center to hold the broach. About 0.02 in. is allowed on the diameter for grinding, and on the spline broaches, about 0.015 in. is allowed on the sides.

A Button Broach

A rather peculiar looking broach is shown in Fig. 131. This is called a button broach, and is used to run through a six-spline gear after broaching, to remove or burnish out any burrs or unevenness, so that the "bores" will all be of exact size. It is not intended primarily to remove any metal; but to provide against possible excessive pressure caused by too much metal, two scraping teeth are provided at *A*. The exact proportions of the type of broach are given in Fig. 132.

SECURING CLEARANCE IN SLIDING GEAR SPLINES

Fig. 133*A* shows the sliding gears and the main shaft of the transmission. This, it will be seen, has three feathers its whole length, on which the sliding gears move and by which they are driven. A close inspection of the end view, showing where the shaft comes through the front gear, will show a plan of providing clearances on broached work, which avoids a large amount of hand work in draw filing corners and in assembling. These clearances are shown at *A* and *B*.

It will be seen readily from this, that a small clearance tooth is raised on each of the cutting portions of the broach, in order to provide the clearances shown and avoid any tendency of binding at the corners. The same effect is produced in the transmission main shaft by having similar projections on the milling cutter in order to produce the groove *B* shown and afford clearance for the inside corners of the broached gear. By this method an extremely small allowance can be made for clearance when the gear is sliding on the shaft, and a first-class fit can be secured without hand work of any kind.

DESIGN OF SPLINE BROACHES

Much that has been said of the solid type of double-keyway broaches is applicable to spline broaches. The main point that has to be considered here is the best method for a proper distribution of the work. There are several ways of designing the teeth, and of these methods two will be discussed. First, the splined teeth of the broaches may be made all one width; that is, if it is desired to have the finished spline 3/8 in. wide, then all the broach teeth will be made to this width or just as much larger as will give a splined hole the keyways of which will be slightly under the predetermined maximum limit.

There are several objections to this method. In pulling out the hole, particularly if the broaches are loaded up—and this must be done, if it is

FIG. 131.—A button broach.

desired to get the maximum output—there will certainly be occasional drags along the side of the spline. Further, with very tough steels there may be

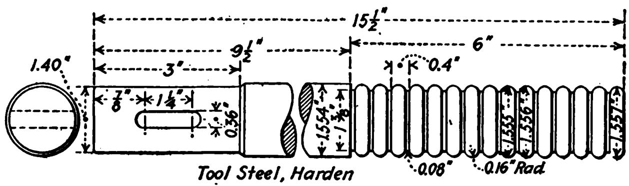


FIG. 132.—Button-broach dimensions.

undesirable drags at the end; sometimes pieces will pull out. Again, with this method all the teeth must be of exactly the same width; and the divid-

FIG. 133*A*.—Transmission gears, showing corner clearance on splined shaft.

ing of the teeth—that is, their angular spacing—must be accurate, or ridges will show on the work.

This extreme accuracy applied to every broach in the set adds to the expense of making them. Apart from this, the question of holding the work to close limits will be more difficult of attainment because of these ridges, and the fact that all the broaches are of the same width generally results in keyways that are more or less tapering toward the hole.

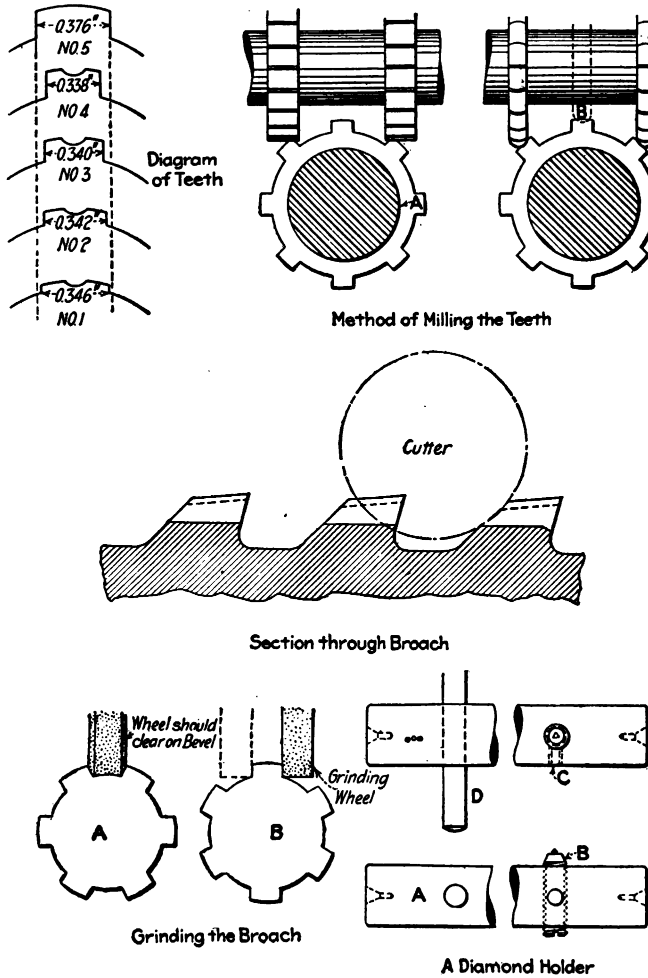


FIG. 133*B*.—Machine operations on spline broaches.

The alternative method is to make the spline teeth of different widths. Suppose that a set of broaches are to be designed to give a hole suitable for a 2 by 1¾-in. shaft having eight ⅜-in. splines. Then the broach teeth will be as follows. Assume that five short broaches are required. The first four broaches should be so proportioned as to diameter that they will bring out the splineways to the full depth, the fifth broach being used to bring them out to the required width; that is, the fifth broach should just take a light cut up each side of the splineways.

To insure that the roughing broaches work easily, without undue friction on the unrelieved sides of the teeth, it is best to have each successive broach with slightly narrower teeth than the preceding one. The sizes that will work successfully for such a set of broaches are given in the diagram, Fig. 133*B*, which shows the teeth exaggerated and superimposed. Some designers give the finishing broach more to do on either side, but I have found that $1/64$ in. per side produces cleaner results together with longer broach life.

Of the many different ways of arranging the roughing broaches so as to take a maximum cut for any given material without loss of efficiency there is no other so effective as that of staggering the teeth of the broach; that is, arranging for successive teeth to cut alternately at the center and corners of the splineway.

The best practice is to have only the last few teeth of the broach, which bring the hole out to the full depth, left unnotched. These unnotched teeth should never have much load and should only be used to give an even appearance to the top of the splineway.

Advantage of Notched Teeth

The greatest benefit derived from the system of notched teeth is found in the fact that less room is required for the chips. It is generally recognized that the longer the hole that has to be broached the wider must be the spacing of the teeth. There are two reasons for this: First, the total load on the broach may be more than the cotter will stand without shearing, if too many teeth are in action together without reducing the load per tooth; secondly, the longer the hole for any given load per tooth the greater the required chip space. Now, for maximum life of the broach a minimum load per tooth is necessary, and consequently for any given length of broach the aim must be to divide the work among the largest number of teeth that is consistent with ample chip space. This, then, is why the notched-tooth system is so effective.

When the teeth are not notched—that is, the chip is full width—the chips pile up in front of the cutting tooth and only about one-half of the space provided is actually used to accommodate chips. On the other hand, when the teeth are notched, the chips do not stay in front of the teeth, but will fall on either side. Thus, for any given load of tooth and length of hole a shorter pitch can be used for notched teeth than for teeth that are of full width. This means fewer broaches to the set, or the same number of broaches may be provided and the load per tooth decreased, thus insuring a longer life.

Staggering the Teeth

The staggering of the teeth may be accomplished in several ways, but the following methods have been well tried out and can be recommended as easy of application and rapid in action. The corner may be quickly removed by means of a pair of straddle mills, as illustrated in Fig. 133*B*.

The mills are set at the correct distance apart to take off two corners at once, as shown at *A*. As the width of the tooth that is left should be constant, then as the height of the teeth is gradually increasing by a definite amount, the knee of the miller must be lowered to allow for this difference in height. For this reason it is best to notch all the corners of each tooth before proceeding to the remaining teeth. The method is as follows: Set the cutters central over the first tooth and take a trial cut; lower the knee and divide; then follow the same process all around, noting the setting of the knee.

If the corners are notched sufficiently, move the table of the miller a distance equal to two pitches and repeat the notching, taking care that at each successive row of teeth the setting of the knee is diminished by the amount of the rise of the teeth. This small amount may be calculated, or it can easily be determined by trial on the first few teeth. By this method the cutting portions of the teeth are of approximately the same width, and this is a very important factor in the cutting efficiency of the broaches.

One setting of the mills—as to distance apart—will do for the set of broaches, because although the chordal distance between each successive set of corners is increased, the width of the straddle mills will cover this difference.

Using 45-Deg. Angle Mills

Another way is to use two 45-deg. angle mills, but the disadvantage of this method is that on the first and second broach, where the height of the tooth is small, unless the mills are quite narrow, enough is not taken off the corner of the tooth. With a pair of mills made specially for the job this disadvantage disappears, but it entails a change in width—spacing of the cutters—to complete a set of broaches.

The groove in the center of the teeth—even numbers—may be cut in a similar manner, but here the varying chordal distance will have its effect. Consequently, the setting of the two half-round cutters should be altered for each broach, as the groove must be approximately central. If the broaches have only a few splines—say of the order of four or five—it will be best to put this central groove in with a single cutter, as shown dotted at *B*. For an eight-spline broach the difference apart of center of the teeth is negligible. For broaches having narrow splines this central groove is best put in with a narrow grinding wheel, dressed to the required shape, after the broaches are hardened and finish-ground on their periphery.

There is another operation in connection with making spline broaches that is worthy of mention, because if it is not properly attended to, the result will be poor holes. Spline broaches work best in holes that are a good fit on the broach bottom. Should the hole be oversize, then the weight of the work would take it over to one side of the broach, with the consequence that the spacing of the splines would not be accurate with the axis of the work. When the next broach is put through, the work may be put on the other way up; and this broach would then probably bind along the side of the spline.

However, the worst feature of badly sized holes is that occasionally some will be small, and then the front of the grinding portion of each tooth may try to take a cut. As there is no relief on this part, naturally, the result of a tight hole is almost invariably a bad tear. For this reason holes that have to be broached with spline broaches should be kept to fairly close limits. As a large number of splined holes have to be ground out after hardening, there is a tendency in such cases to allow a wider limit in the hole than is desirable; but for the reasons given, it is unwise, and it is sound practice to hold all such holes between grinding size and minus two-thousandths of an inch. With such limits the broaches must be made so that the minus-sized holes will go on.

To prevent any possibility of the guide portions of the teeth tearing, the front of each guide should be rounded or beveled off. This can be readily accomplished by dropping a small milling cutter—of the right curvature—on the front of each guide, as shown in the section through broach (Fig. 133*B*). This puts a distinct bevel on the front edge and entirely prevents any tendency to drag. The beveling done by the cutter may be supplemented by forming a radius with a file; but this is a slow process, and unless the rounding off is well done, it will disappear when the guide portion of the broach is ground.

Grinding Spline Broaches

To grind spline broaches, no special machinery is needed, but accurate and careful methods are necessary. Where spline broaches are required, a Bath spline grinder is most useful. When such a machine is available, the grinding of the broaches is considerably simplified. On this machine there is provision for dividing and indexing the broaches, and there is also an attachment for giving the grinding wheel the correct curve. The wheel-truing attachment will also bring the sides of the wheel to the shape required to grind the sides of the splines, but in the case of broaches the wheel should never be allowed to work on the body of the broach and the sides of the teeth at the same time.

The reason for this is as follows: When the grinding wheel passes along the broach, there is sure to be some slight springing of the broach. As the wheel passes off a tooth, the broach rises slightly, with the result that if the grinding wheel is grinding the sides of the teeth, these will be somewhat smaller back and front than in the middle; that is, there will be a high place on the center of the tooth. This means of course that the teeth will bind in passing through the work and will need to be relieved before they will produce the desired result. The best way to grind the broaches is to grind the body first, as shown at *A*, in lower part of Fig. 133*B*, and then to grind each side of the teeth with the flat side of a wheel, as shown at *B*.

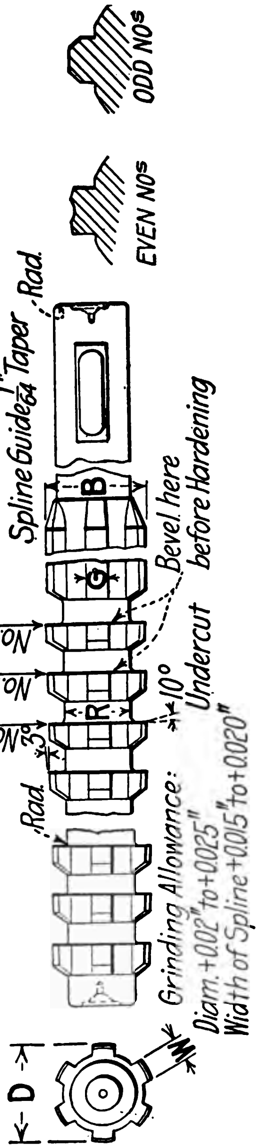


FIG. 134.—Style of drawing for broach.

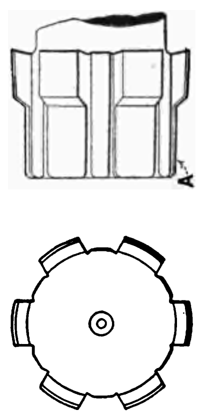


FIG. 135.—Enlarged view of broach end.

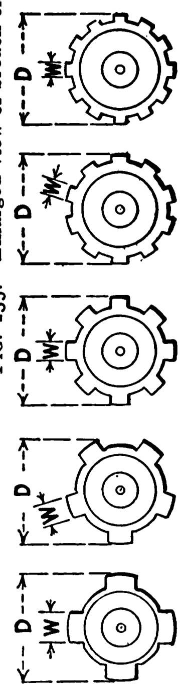


FIG. 136.—Auxiliary broach sheet.

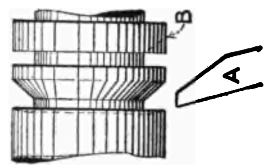


FIG. 137.—Method of making the blank.

After grinding one side of all the teeth with the wheel in the position indicated by the full lines, the wheel should be reset to the position shown dotted and the other side of the teeth ground. As there is a possibility of some of the teeth being scant—owing to distortion in hardening—it is always advisable to go over the teeth twice, first roughing them down to within a few thousandths of an inch of size, then with a nice true clean-cutting wheel bringing them to size.

But while a Bath spline grinder is a convenience in making broaches, it is not absolutely necessary, because the grinding may be done on any tool grinder that has a table of sufficient length. The requirements are means of accurately indexing the broach and some arrangement for turning the wheel to the desired curve for the body. The dividing head of a miller may be readily adapted to the grinder for indexing the broach. The diamond holder shown in Fig. 133*B*, although crude, will true the wheel to the desired radius.

In this device the bar *A* is a piece of cold-rolled steel drilled and tapped at one end for the screw *B*, into which a small diamond is set. When the diamond is set to the required radius, the grubscrew *C* locks it in position. The length of the stock *A* should be the same as that of the broaches to be ground. There is then no need to move the centers of the dividing head in order to use the diamond. In utilizing this device the broach is removed from the centers and replaced by the wheel-truing fixture. The grinding wheel is brought directly over the diamond and the radius is swept out by oscillating the diamond by means of the pin *D*, driven into the other end of the stock.

In Fig. 134 is shown a standard for spline broaches. It will be noticed that a short plain piece is left on the end of the broach. This is shown to a larger scale at *A*, Fig. 135. Both in making the broaches and in subsequently grinding them this plain portion will be found convenient for the application of the carrier to drive them. When broaches are made without this piece, the end teeth frequently get damaged by the carrier.

To prevent mistakes it is best to paste on the drawing an end view showing the correct number of splines. An auxiliary tracing should be made, showing all these end views, to the same scale as the standard sheet; and one of the blueprints from this can be cut up and the correct view pasted in position. The auxiliary sheet would look like Fig. 136. The slope for the back of the tooth may be expressed as a dimension, but it has been found more convenient to express it as an angle. This really depends on the method of turning the broaches.

The method used by the writer is shown diagrammatically in Fig. 137 and is as follows: After the broaches are turned, the teeth are spaced by means of a parting tool taken down to the full root depth. After this slope is put on by means of the tool *A*, which is fed in the correct angular direction, the slide of the lathe is set to the angle given on the standard sheet. The final operation on the teeth, which is turning the 10-deg. undercut on the face of the teeth, is performed as indicated by the tool which is fed in at 10 deg.

A table of dimensions may be filled out in various ways. One method is to give the dimension of every tooth so that at any time by counting the number of teeth on the broach its dimensions may be taken directly from the table. Another way is to figure the first tooth and the last effective tooth, also the few idle teeth at the end.

The method of grinding the tops of the teeth is as follows: The last few, or idle, teeth are ground parallel, and the first tooth is ground to size. The grinder is then set for a taper that will join these teeth in one slope. Afterward the table of the grinder is set to 3 deg., and each tooth is backed off to a cutting edge. By applying Prussian blue to the teeth before starting to back them off, the relieving can be performed expeditiously, because the blue is distinctly visible while the work is revolving and forms a good guide as to when the tooth has acquired a cutting edge. This is of course when the blue is just about to disappear.

The experience gained from previous sets of broaches, taken in combination with the conditions to be met, is the best guide in designing new sets. Experience is always valuable, but tabulated experiences are the most reliable, as they do not depend on memory. For this reason ample notes of each set should be taken, together with the conditions under which they worked and how they performed. The data sheet I have used for some years is given in Table V. It gives the size of broach and number of splines, number of broaches to a set, load per tooth, and is filled in with the data of a few successful sets.

To use this data sheet when a new set of broaches are made, the details are entered on the sheet. Each fresh set is given a reference number on the data sheet, and this reference number always prefaces any entry that is made in regard to the operation of the broaches, the length of the work and the material broached. By such a procedure

Table V.—Data for Spline Broaches

Nominal size of splined hole		Number and width of splines		Number of broaches in set		No. of teeth per broach	Pitch of teeth, in.	No. of effective teeth	Total length of broaches, in.	Diameter of root or bottom of clearance space, in.	Approximate diametral load per tooth in 0.001 in., number of broach						
Inner diameter, in.	Top of splines, in.	Number	Size, in.	Roughers	Finishers						1	2	3	4	5	6	7
1¼[1]	1 21/32	5	7/16	4	2	32	5/8	30	31	1 3/16 to 1	4	4	4	3	7	7	
1½[1]	2 1/32	5	9/16	4	3	32	5/8	29	31	1 1/16 to 1¼	4½	4½	4½	4½	6	6	6
1⅝	1 57/64	4	5/8	4	1	32	5/8	29	31	1⅛ to 1 5/16	2½	2½	2½	2	10		
1 13/16	2 1/32	8	3/8	3	1	33	5/8	29	31½	1¼ to 1⅜	2½	2½	2½	8			
1⅞	2 5/32	6	½	3	1	32	5/8	28	31½	1¼ to 1⅜	3½	3½	3½	10			

[1] Twice the usual depth.

all notes relating to any particular set are brought together; and used in conjunction with the data sheet, they form a reliable guide for the design of any subsequent set.

REPAIR AND UPKEEP OF SPLINE BROACHES

The repair and upkeep of broaches, says Walter G. Groocock, in the *American Machinist*, is such an important item that the broach designer must of necessity pay some attention to this side of the subject. It will be readily recognized that the life of a set of broaches depends very largely on the attention they receive after they are put to work. Consequently, the design should be such that careful attention will prolong the life of the broaches without any sacrifice of accuracy or utility.

Spline broaches should never have dead sharp corners on the cutting teeth, except for the last few teeth of the finishing broach. It will always be noticed by any close observer of broaching that the corners are the first to fail. This, of course, is in accord with a turner's experience with a parting tool. If the sharp corners of the broach teeth are just rubbed off with an oilstone so as to give about $1/100$-in. radius, they will stand up much better than if they are left quite square; and if the corners are subjected to periodical examination and those teeth showing any signs of wear are touched up, then the life of the broaches will be prolonged.

When working on very tough or hard materials this periodical examination is absolutely essential, because one bad tooth on a spline broach will soon bring disaster to other teeth near it unless some precaution is taken. The preventive means that may be adopted are various and will naturally depend on the disorder; but whatever the method adopted, it must be such that no double load can fall on the teeth following. When a tooth is bad—that is, is beyond the usual point where a local sharpening will give it a fresh lease of life—the best thing to do is to grind it until it presents a cutting edge. As it will not, when so treated, do any real cutting, the work it should have done must be shared among, say, the next four teeth in order.

Thus, suppose the load per tooth on a broach is 0.004 in. and a tooth has failed; then instead of the next tooth to it having to take 0.008 in., as it would have to do if the broach was left in its damaged condition, the next four teeth to the damaged one should be ground so that each of them will take a cut of 0.005 in. The question may be asked, If the damaged tooth will not cut, why grind it to a cutting edge?

Teeth that have to be ground below the cutting line should always be ground so as to cut, because there is always a distinct possibility of pieces of chip getting in front of them; and if the tooth has a cutting edge, no harm will result. On the other hand, should it be just roughly rounded off and a chip get on it, a bad rub will result in the broach getting crowded to the opposite side of the hole, with the possibility of serious damage.

Reason for Grinding Bad Teeth

There is yet another very good reason why the bad teeth should be carefully ground to a cutting edge and not merely rounded off. Accidents will happen; and after a time, particularly with spline broaches working on tough alloy steels, so many of the teeth get chipped and show signs of failing at the corners that it is necessary to do something that will keep the broaches in service. This may be accomplished in several ways; for instance, another broach may be made to replace the damaged one, or an extra broach may be put in the roughing set and by so doing reduce the load per tooth.

To take a concrete case for an example, suppose a set of broaches used for pulling out a 2 by 1¾-in. six-splined hole is in bad order. There are four broaches to the set (roughing), each having 32 effective teeth. Then the diameter increase per tooth would be $\frac{250}{128} = 0.002$ in. per tooth or, say, 1/16 in. per broach. Now if it is decided to have only four broaches to a set, then a new No. 4 broach must be made; and Nos. 2, 3 and 4 must be ground respectively to the sizes required for Nos. 1, 2 and 3. Properly case-hardened broaches should always have a good 1/16 in. of case, and consequently by reducing the broaches as mentioned the case-hardening will have been ground only about halfway through.

If, on the other hand, the broaches are thought to have been overloaded and it is decided to introduce another broach to ease the load per tooth, then only sufficient should be ground from No. 1 to make it clean up; and serving the others the same quite possibly would only need about half the teeth on the additional broach to cut, leaving the other half available for subsequent grindings to bring the corners into good condition.

The Question of Reserve Teeth

The question of having a reserve of teeth is one that is closely allied to the design of the broaches. All new broaches should have several teeth at the back end that do not cut when first used, and these teeth will be available when grinding takes place. To illustrate this point, take the case of a broach with 36 teeth, the total increase in diameter of which is to be 1/16 in. Now the broaches may be made by spreading this work over the whole of the 36 teeth, or 0.002 in. per tooth can be taken and leave four teeth idle. This latter is to be preferred, because when the corners are bad the face of the teeth can be ground; and this will reduce their diameter so that after a few grinds it will be found that there are only three idle teeth.

Apart from this orthodox grinding of the face of the teeth the corners may, through mishandling, wear, etc., get into such a poor condition as to necessitate grinding the tops of the teeth, as mentioned before. If three idle teeth are in reserve, this means that the diameter of all the bad teeth can be reduced by 0.006 in.—quite an appreciable amount to grind off—and still have the broach the same size at its finishing end. For this reason alone, short spline broaches should never be designed to have less than four idle teeth each, and on finer pitches six teeth would be preferable.

Another point in connection with the making of broaches, which will materially assist in their maintenance, is this: After the broaches have been in use for some time and require sharpening, they will be found to be sprung out of truth. If the sharpening is to be just a local grinding of the face, this error from truth will not matter; but should it be desired to grind the tops of the teeth, then naturally the broach must run true before the wheel can be applied to it.

If, when the broaches are made, one of the chip grooves about the middle of the broach is also ground concentric with the tops of the teeth, then when it is desired to grind the tops after use, the work can be kept running true on the grinder by running on a small steady-rest.

BROACHES FOR MOTORCYCLE GEARS

The broaches shown at *A*, *B*, *C* and *D*, Fig. 138, are used at the factory of the Pierce Cycle Co., Buffalo, N. Y., for the purpose of broaching quadruple keys in steel gears used in motorcycles.

Owing to the toughness of the steel gears, and the fact that sharp-cornered keys are wanted, four broaches are used. The broach *A* cuts away the greater part of the metal between the keys and has 32 teeth of 0.50-in. pitch, which increase in diameter by 0.005 in. each, from start to finish, except the last, which is only 0.003 in. larger. The chip clearance is 0.375 in. wide and has an angle of 30 deg. back of the tooth, and is slightly undercut at the cutting edge to curl the chips. This leaves a land back of the cutting edge 0.125 in. in width.

The main tooth dimensions of *B* and *C* are the same as for *A*, except that the teeth increase only 0.0025 in. in diameter. The finishing broach *D* is considerably shorter and less expensive to make when it gets worn undersize, there being only 11 teeth of 0.05-in. pitch, having a land 0.187 in width. The chip clearance at the back is 30 deg. and there is 10 deg. undercut to the cutting edge.

The gear blanks, in this case were 2 in. thick and made of 3½ per cent. nickel steel, 0.20 to 0.30 point carbon.

DESIGN OF DIAGONAL-TOOTH BROACHES

The broaches here shown represent the shop practice of the Davis Boring Tool Co., St. Louis, Mo., and are the ones used in the machine shown in Fig. 62. In Fig. 139, *A* is a very large broach for finishing the ends of rectangular holes. *E* and *B* are a pair used for finishing the ends and sides of

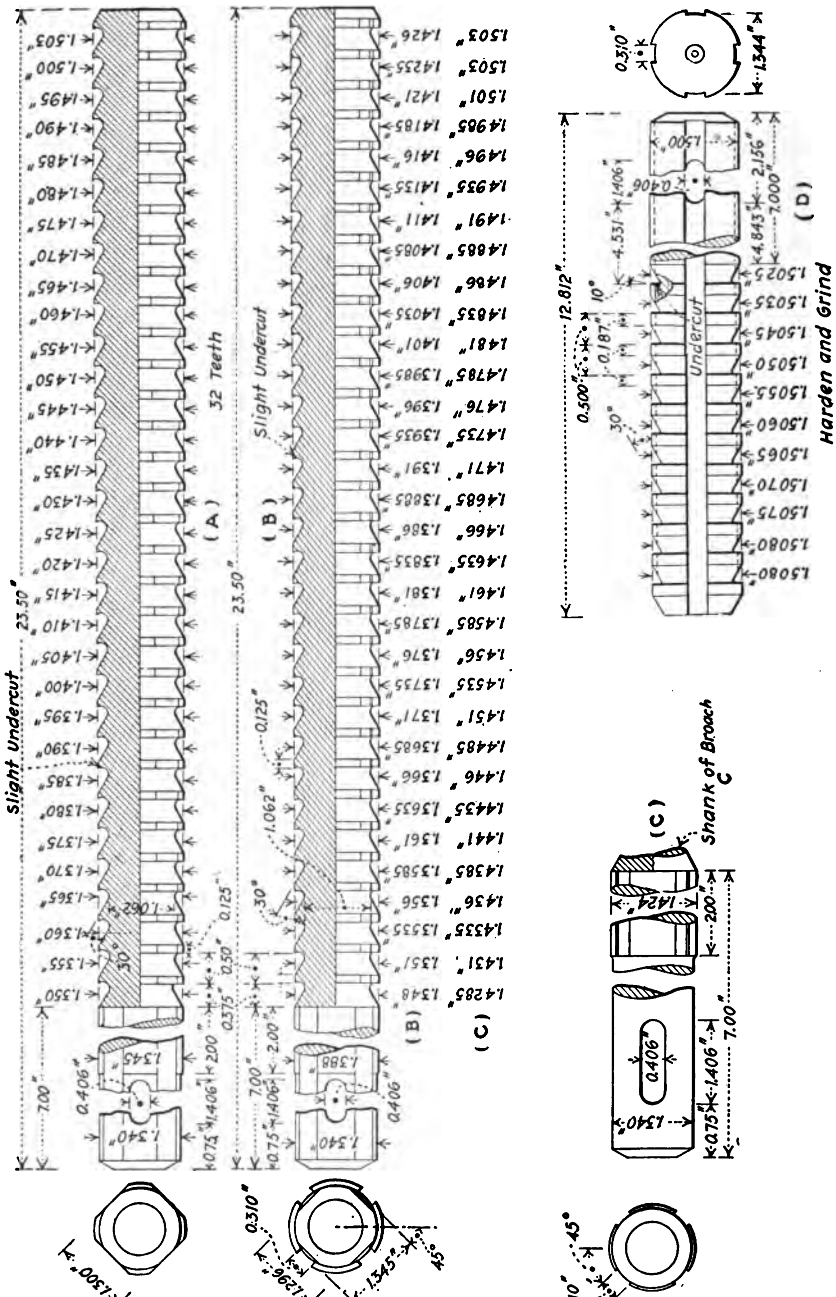


FIG. 138.—Broaches for four feather motorcycle gears.

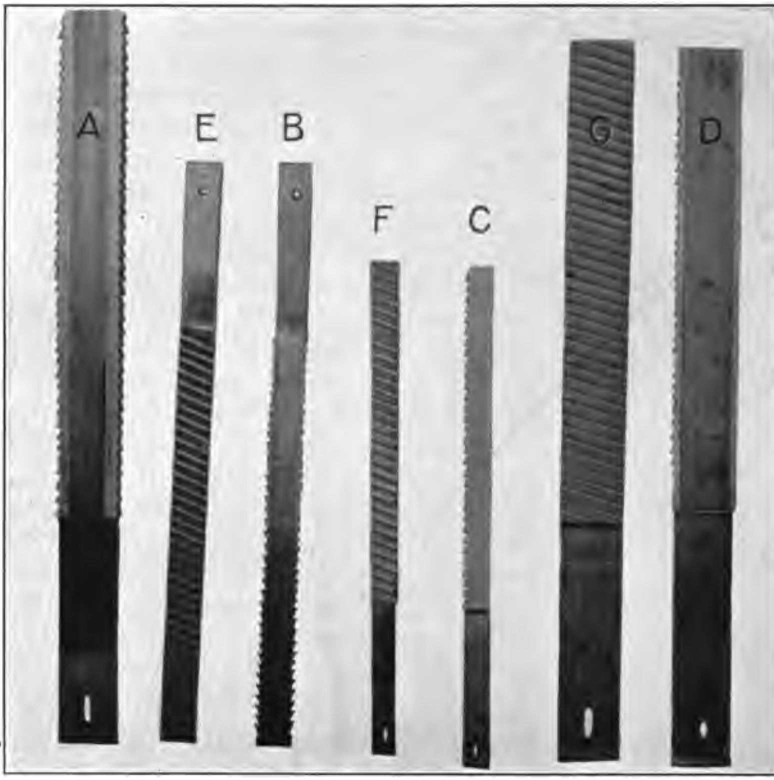


FIG. 139.—Diagonal-tooth broaches for rectangular holes.

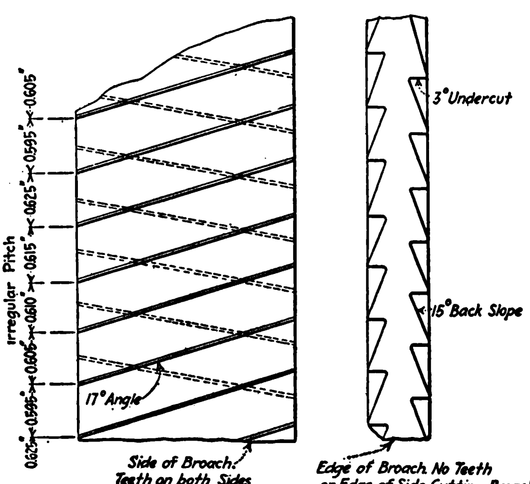


FIG. 140.—Proportion of diagonal-tooth broaches.

a smaller hole of the same shape. *F* and *C*, and *G* and *D*, are also pairs used for the same purpose. Details of the design of these broaches are given in Fig. 140.

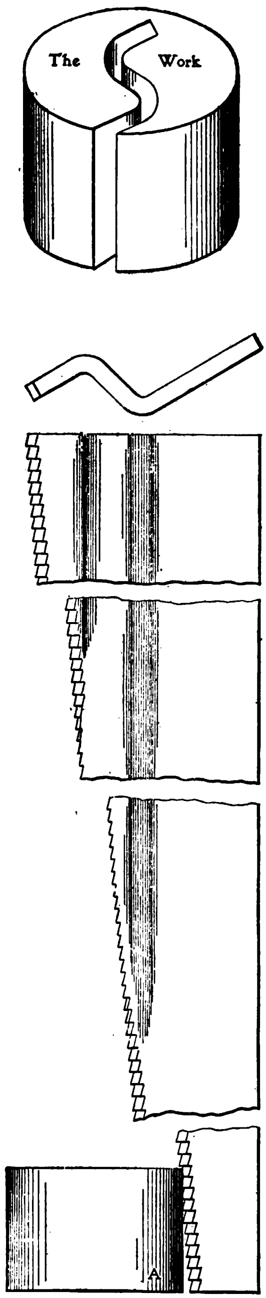


Fig. 141.—Broach for cutting crooked key slot.

The broaches are made of both high-speed and carbon steel, the latter being preferred for accurate finishing, as it keeps a keen edge longer. The teeth are undercut and diagonal. The opposed sets of cutting teeth are balanced to prevent the tendency to creep. The tendency to chatter, so troublesome in many cases, is overcome by differential spacing of the teeth, in addition to the shearing angle. The sizes used vary from 1/4 by 1 5/16 in. to 1 by 3 7/16 in. in cross-section, and from 16 to 24 in. in cutting length. The main proportions of the teeth are the same for all sizes, as can be seen from Fig. 140. It will also be seen that the angle gives a shearing cut of great efficiency in steel, and the undercut curls the chip nicely. The taper per foot varies somewhat, but is usually about 0.015 in. for the roughing, and 0.009 in. for the finishing broaches.

KEY-SLOT BROACH

The broach and sample of work shown in Fig. 141 were first shown in the *American Machinist* April 3, 1903. With broaches of this type, slots of all sorts of shapes may be made from the complicated paracentric slots of the Yale locks to simple curves or the common straight slots. When made of thin saw metal, a heavier back is used to prevent springing or buckling on the cut. In the illustration a piece of work in position for the broach to start the slot is shown at *A*. A broach of this character must naturally be rather long in order to have slope enough to cut the slot at one pass. No exact details of the tooth spacing or other details of this broach are obtainable, but the principle will be easily understood by any mechanic.

INSERTED-TOOTH BROACHES

As a general rule, inserted-tooth broaches are unsatisfactory, but two broaches are shown in Fig. 142 which are used in one of the plants of the

International Harvester Co., to broach keyways in heavy traction-engine flywheels. The bodies of these broaches are made of machine steel, and the cutter blades are inserted in slots milled in the bodies. The one at the back has staggered teeth, made by inserting two blades in the same slot side by side, but with the teeth set as shown.

FIG. 142.—Two inserted-tooth broaches.

AN ADJUSTABLE BROACH

E. A. Suverkrop writes as follows:

A Colt automatic-pistol stock, the hole in which is finished by broaching, is shown at *A*, Fig. 143. Considerable trouble was at first encountered in broaching these pieces. Three sides of the hole are finished, while the fourth, which is left

FIG. 143.—The work and the broach.

half-round as it comes from the Pratt & Whitney slot miller, acts as a guide or bearing for the fourth side of the broach, which has no teeth.

The original broaches were made with teeth at right angles to the direction of the cut and gave poor results. The spaces became choked with cuttings and sometimes the work was torn to pieces by the broach. The broach shown in Figs. 143 and 144, was then made. In it the teeth are at an angle giving a shearing cut. A tapered gib *B* is fitted at the back end of the broach and can be adjusted by the screw *C* to compensate for the wear of the teeth and thus retain the depth of the slot in the work. This dimension is important.

With these broaches the operator can turn out 200 pistol stocks a day. One broach has finished as high as 8000 pieces.

BROACH HOLDERS OR COUPLINGS

There are numerous ways of coupling the broach shank to the drawhead of the machine, the simplest being a sleeve into which the end of the broach

FIG. 144.—Showing the wedge adjustment.

shank is slipped and fastened by means of a cotter pin run down through slots in the sleeve and broach end. On many small broaches, an adapter is screwed onto the end of the shank, the adapter fitting the sleeve on the drawhead. The use of this kind of an adapter makes it necessary to only have one adapter for a number of sizes of broaches, the shanks of these broaches all being threaded alike. As a rule, an adapter of this kind which is made to screw onto the end of the broach, should have some means of locking or clamping it securely to the thread to prevent any tendency to loosen or twist as the broach is pulled through the work. This can be done by splitting the threaded sleeve or nut and using a clamping collar with a setscrew in it, placed over the end of the sleeve. Another but not such a satisfactory way for commercial work is to use one or more setscrews in the sleeve itself, the ends of the setscrews being "padded" with brass where they come into contact with the thread of the broach shank. If any "float" is required, it can be given by having the cotter a loose fit in the coupling slot.

Several kinds of couplings have already been indicated, and two shown in Figs. 39 and 111 respectively. The first shows the split-cotter type and the second the toothed-wedge type, and need no further description here. Two other kinds of couplings are shown in Fig. 145. The one at the right is a modification of the split-cotter type and is used for broaches with round shanks notched on each side, and when in use is fastened to the draw spindle with the square end outward. The slide is then dropped down till the round

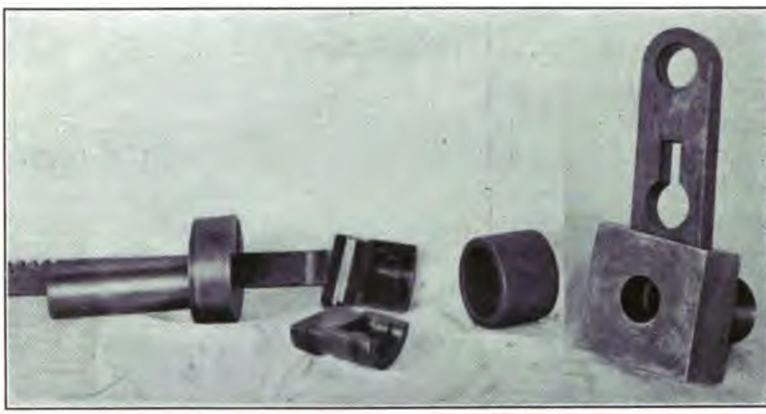


FIG. 145.—Broach holders.

part of the slot is opposite the hole in the square block. The notched shank of the broach is now inserted and the slide allowed to drop down, the rectangular slot of the slide fitting over the notched place in the shank, locking it securely to the spindle.

The other holder is used for keyway broaches made of a single bar of steel of rectangular cross-section. In order to use this type of holder, the draw spindle must either be grooved all around close to the end, or else fitted with a cap or adapter turned down on the end and grooved to suit. The lock itself consists of three parts—two semicircular pieces and a collar. But one groove is cut in the flat broach shank, and one of the semicircular pieces has a key running crosswise, that fits this groove. The opposite end of both pieces is chambered out, and has a circular key in it to fit the groove on the draw spindle. In using this holder, the collar, shown in the middle, is slipped on over the draw spindle, the two semicircular pieces are placed together over the end with the broach shank between them, and then the collar is slipped over all, locking broach and draw spindle together securely, but allowing a certain amount of play, which is essential in practically all holders used for this purpose.

At the left in this cut, is shown the end of a cutter-bar or keyway broach resting in the slot of a work bushing, used to guide the tool while cutting.

FIG. 146.—An eccentric coupling lock.

AN ECCENTRIC LOCK

Another quick-acting and very satisfactory coupling lock is shown in Fig. 146 and in detail in Fig. 147. This type was developed in the shop of Brown & Sharpe, Providence, R. I., and is used for the broaches shown in Fig. 123, which have a rounded recess milled in one side of the shank. The

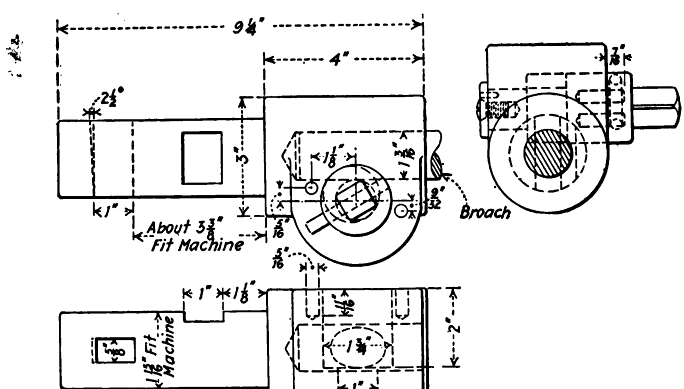


FIG. 147.—Details of an eccentric lock.

holder is held in the drawhead by means of a pin through the shank, and is positioned by a setscrew. The eccentric is operated by a T-wrench, and stop pins on the collar of the eccentric limit its movement to the on and off positions.

On some machines a threaded sleeve is screwed directly into the drawhead. These sleeves are split and threaded to receive the coupling proper, which is attached to the end of the broach shank. The drawhead and sleeve made by the Lapointe Machine Tool Co., shown in Fig. 148 illustrate this method. For use in this type of head sleeve, the couplings used in the Alco shop are especially adapted. These couplings are shown in Fig. 149.

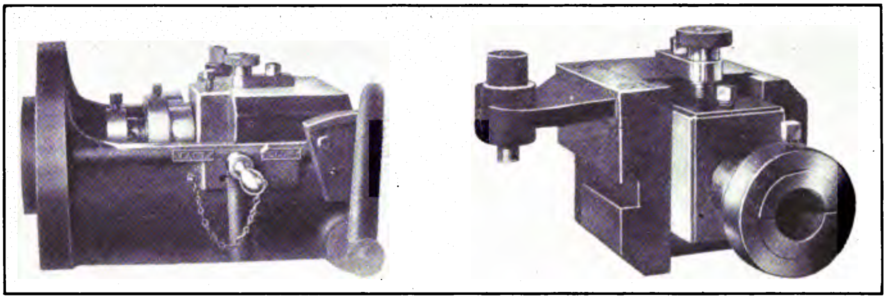


FIG. 148.—Threaded draw-head sleeve.

In this shop there are two common types of locks used to fasten the broach shank into the coupling, one is the straight and the other the forked key the couplings for these being shown at *A* and *B* respectively. The former is usually used on large broaches with round shanks of sufficient size and

FIG. 149.—Various types of couplings.

strength to stand having a slot cut through them for the key. The other type is used for smaller broaches having a notch on each side of the shank near the end.

The coupling *C* is used for three different keyway broaches of rectangular cross-section. The coupling shown at *D* was designed at the Alco shop to hold very small broaches which it was undesirable to either slot or notch. The holding device consists of two jaws, like chuck jaws, set into a turned block, and operated by a hand screw, as shown.

WORK BUSHINGS AND WORK-HOLDING FIXTURES

Besides the work bushings and holders for the common run of work, there are numerous indexing work holders for special or unusual jobs, but as these usually have to be designed specially in each case and fitted to the face-plate of the machine, no further mention need be made of them except what has already been touched upon in a general way. A number of bushings are shown in Fig. 150. The one at *A* is used to cut two keyways at right angles to each other. Two broaches are not used, but one keyway is broached, then the piece is turned till the keyway is coincident with the blank slot, after which a key is thrust in to hold the work while the other keyway is broached.

This differs only slightly from the one shown at *A*, Fig. 111, which can be used only after the keyway is broached on another holder. Again referring to Fig. 150, the bushings *B*, *C* and *D* hold work with taper holes, and *E* with a straight round hole. The bushing *F* is for locating a small lever in which a square hole is broached, the lever being placed lengthwise of the groove across the end of the bushing. Only part of *H* shows, the other part being the same as the part shown. This is used to locate a certain size gear, the teeth of which fit the guides on the inside of the uprights.

Another work holder for gears is shown in Fig. 151. The keyways cut with the gear held on this bushing will have a definite relation to the teeth, one of which fits between the two teeth at *A* on the locating block. This block is adjustable, so that gears of different diameters may be placed on it.

GEAR HOLDING AND MARKING FIXTURE

Where a chain or set of gears to be keyseated, bear a certain definite relation to each other when assembled, it is a good plan to place a mark on each near the teeth to assist in the setting in the first assembly and also in any future operations.

The superintendent of Haberer & Co., Cincinnati, Ohio, has designed a set of fixtures, for marking each gear used in their car, not only in definite relation to the keyway cut, but also to the particular meshing tooth. Fig. 152 shows three of these fixtures used for crank, camshaft and magneto gears. The gears are in each instance slipped into place over slotted work bushings in the center, through which the broach moves. A dog or locking pin, fitting between two of the teeth in each gear, holds them in place. A single marking punch, carried in a hinged holder, is used on each of the two left-hand fixtures. The right-hand one has two of these marking punches.

It will be seen that a light tap on the marking punches with a hammer, before the broached gears are removed, will leave a guiding mark, showing how to set them when assembling. This system is applicable to many

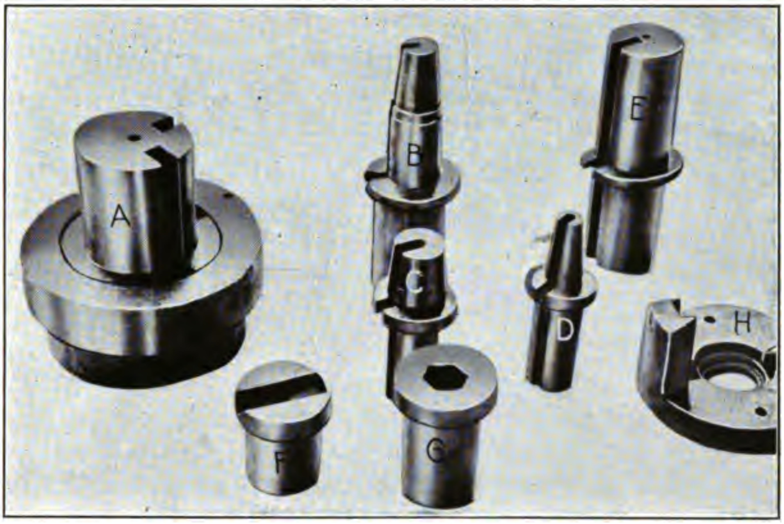


FIG. 150.—Several kinds of work holder.

jobs of duplicate work, and may be used on almost any broaching machine, of either the push or pull type.

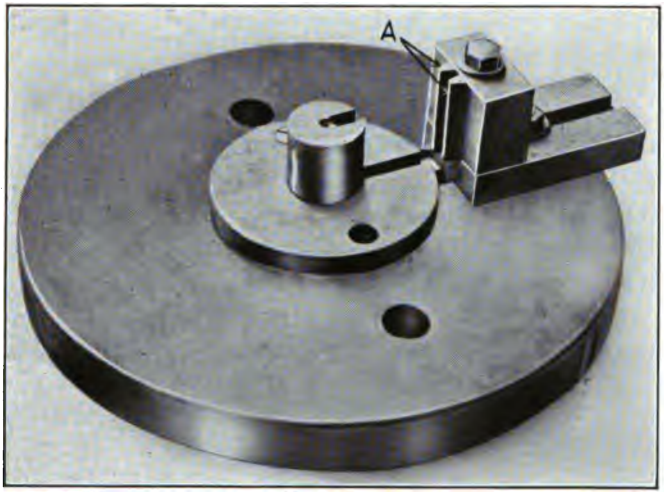


FIG. 151.—Adjustable holder for spur gears.

A MOTOR-CAM FIXTURE

A little fixture used for holding cams while broaching the keyway is shown in Fig. 153. The use of a fixture like this insures the keyway being cut in the proper relation to the rise of the cam. The part in which the broach slides is an ordinary work bushing. Doweled to this is a plate

FIG. 152.—Gear keyseating and marking fixtures.

FIG. 153.—Cam fixture.

carrying a slide with a V-cut in the lower end. This slide is moved by means of the thumb-screw shown, so that when the cam is slipped into place, a slight turn of the screw will lock it in position.

CHAPTER VI

THE DESIGN OF PUSH BROACHES

While the formulas, tables and rules given for pull broaches apply in a general way to the push type as far as the pitch and contour of the teeth is concerned, there is considerable difference in the length of the broach itself, due largely to the fact that a push broach must be made stiff enough to not spring or buckle as it is forced through the work. Probably the first real broaches made were push broaches, but at present they are not nearly so extensively used as the pull type. Definite rules for the design of push broaches that will fit every occasion are not available. A prominent manufacturer and engineer, who has probably had more to do with push-broaching work than any other one man, in answer to a question put to him 2 or 3 years ago regarding a formula for push-broach teeth, wrote as follows:

We started out years ago with formulas but various conditions caused these to be modified in such an empirical fashion that there is little left that could be called a formula. As a matter of fact, we have learned by experience what is required to meet certain conditions and the broaches are designed in that way.

We find that the depth of cut which of course is a function of the pitch can be very materially increased in the case of square broaches as the corner is approached. The pitch of the entire set is maintained constant as a matter of convenience, while the amount of cut taken per tooth is frequently as much as six times as great near the end of the last broach as it was at the beginning of the first one. Whether or not an empirical formula could be worked out from the figures representing our present practice, I cannot say at the moment, not having had occasion to look the subject up from that standpoint.

My impression is that investigation would show that the pitch of the teeth is just about as logical as the width of keys which are used with given diameters of shafts, that is the width and depth of keys are as you know largely a matter of individual design, although there are several standards any one of which is not very closely followed and have all been worked out from practice, and in any given series of sizes the proportions in common practice do not bear any uniform relation to the diameter of shaft with which any given size is used.

I should say offhand without investigation that the pitch of the broach teeth would fall into the same class of data.

TABLES OF PUSH-BROACH DIMENSIONS

Fortunately we are able to give in this chapter an unusual number of tables, compiled from actual shop practice, to guide the designer of push broaches in his work. The Spicer Manufacturing Co., Plainfield, N. J., does a tremendous amount of accurate broaching in connection with the manufacture of its universal joints, and the results of its years of experience in the design of broaches is extremely valuable. The tables, worked out from actual practice at the Spicer shop, for machining forgings of 40-point carbon steel, will give first-class working data.

It will be noted that where the length of the hole varies, allowance is made in the tooth proportions, in order to equalize to some extent the power required to force the broach through, and in making similar broaches these tables may be used as guides for others approximating the same dimensions. These broaches are used in Watson-Stillman 20-ton hydraulic presses, the average time required to force a broach through and return the ram to the starting point being between 10 and 15 sec., varying slightly with the different sizes.

The tables for round-cornered, square broaches need little explanation other than to call attention to the fact that the cutting teeth are all developed on the corners, the flat sides being milled the same and not "stepped" as usual, an advantage which will be gone into more in detail in another article describing the making and use. Attention is also called to the ample chip space and curve of the fillet at the root of the teeth, without which a broach is useless in steel, and to the fact that the first, or pilot teeth, are the same dimensions as the last teeth of the preceding broach.

On the six-spline broaches, the method of breaking up the chips by grooving alternate teeth is worth noting, as well as the improved form of teeth, which are the design of Mr. Spicer. These teeth give the maximum chip clearance; maximum strength with the minimum of metal, allowing closer spacing of the teeth, and consequently less broaches to a set, to produce accurate results, though, of course, closer-spaced teeth mean more power to force through. The ten-spline broaches have in addition to the improved form of teeth, a special design of pilot teeth which makes it easier to start them quickly.

In the first table, the grinding allowance is as low as 0.006 in., and in two cases—the ½- and 9/16-in. square broaches—it is 0.010 in.; but in a majority of cases the allowance is 0.032 in., or approximately 1/64 per tooth, for both square and multiple-spline broaches.

In all cases, except the 3-in. size, the butt end of the broach is made somewhat cone-shaped, to fit the cupped end of the push pin in the press ram, which automatically centers and lines it up, the work hole, of course, being placed directly in line. The serial numbers of the broaches indicate in each case the number used in a set to complete the size of hole specified.

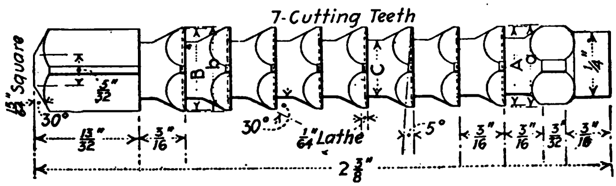


TABLE VI.—DIMENSIONS OF 1/4-IN. SQ. BY 5/16-IN. BROACHES

For Hole 1 in. Long

No.	Lathe dimensions				Grinding dimensions	
	a in.	*b* in.	*c* in.	*c* ft.	*A* in.	*B* in.
A-1	0.256	0.260	11/64		0.250	0.254
A-2	0.260	0.266		3/16	0.254	0.260
A-3	0.266	0.274	3/16		0.260	0.268
A-4	0.274	0.284		13/64	0.268	0.278
A-5	0.284	0.295	13/64		0.278	0.289
A-6	0.295	0.307		7/32	0.289	0.301
A-7	0.307	0.328	7/32		0.301	0.322

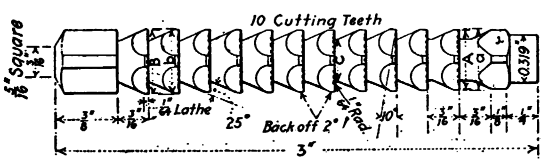


TABLE VII.—DIMENSIONS OF 5/16-IN. SQ. BY 27/64-IN. BROACHES

For Hole 1/2 In. Long

No.	Lathe dimensions				Grinding dimensions	
	a in.	*b* in.	*c* in.	*c* in.	*A* in.	*B* in.
AB-1	0.342	0.349	13/64		0.322	0.329
AB-2	0.349	0.361		13/64	0.329	0.341
AB-3	0.361	0.377	1/4		0.341	0.357
AB-4	0.377	0.397		17/64	0.357	0.377
AB-5	0.397	0.422	9/32		0.377	0.402
AB-6	0.422	0.452		19/32	0.402	0.432

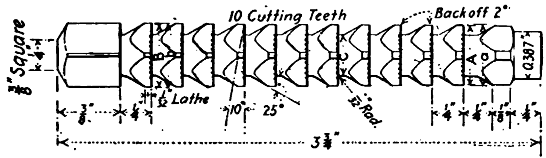


TABLE VIII.—DIMENSIONS OF 3/8-IN. SQ. BY 31/64-IN. BROACHES
For Hole 1¼ In. Long

No.	Lathe dimensions				Grinding dimensions	
	a in.	b in.	c in.	c in.	A in.	B in.
B-1	0.410	0.417	9/32		0.390	0.397
B-2	0.417	0.429		9/32	0.397	0.409
B-3	0.429	0.445	19/64		0.409	0.425
B-4	0.445	0.465		5/16	0.425	0.445
B-5	0.465	0.490	21/64		0.445	0.470
B-6	0.490	0.519		11/32	0.470	0.499

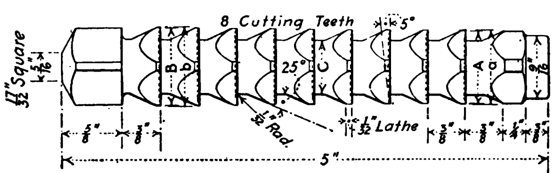


TABLE IX.—DIMENSIONS OF 9/16-IN. SQ. BY 11/16-IN. BROACHES
For Hole 1½ In. Long

No.	Lathe dimensions				Grinding dimensions	
	a in.	b in.	c in.	c in.	A in.	B in.
D-1	0.570	0.580	3/8		0.560	0.570
D-2	0.580	0.592		3/8	0.570	0.582
D-3	0.592	0.606	13/32		0.582	0.596
D-4	0.606	0.623		13/32	0.596	0.613
D-5	0.623	0.644	7/16		0.613	0.634
D-6	0.644	0.670		15/32	0.634	0.660
D-7	0.670	0.700	½		0.660	0.690

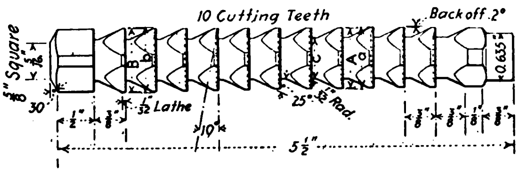


Table X.—Dimensions of 5/8-in. Sq. by 3/4-in. Broaches
For Hole 1 In. Long

No.	Lathe dimensions				Grinding dimensions	
	a in.	*b* in.	*c* in.	in.	*A* in.	*B* in.
E-1	0.665	0.700	7/16		0.640	0.675
E-2	0.700	0.745		15/32	0.675	0.720
E-3	0.745	0.790	1/2		0.720	0.765

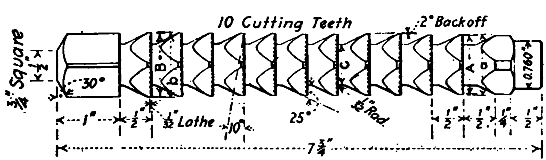


Table XI.—Dimensions of 3/4-in. Sq. by 1-in. Broaches
For Hole 2 1/2 In. Long

No.	Lathe dimensions				Grinding dimensions	
	a in.	*b* in.	*c* in.	in.	*A* in.	*B* in.
F-1	0.790	0.815	17/32		0.765	0.790
F-2	0.815	0.845		9/16	0.790	0.820
F-3	0.845	0.885	19/32		0.820	0.860
F-4	0.885	0.935		5/8	0.860	0.910
F-5	0.935	0.985	21/32		0.910	0.960
F-6	0.985	1.040		21/32	0.960	0.015

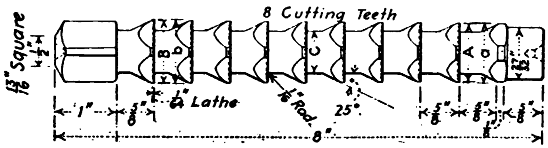


TABLE XII.—DIMENSIONS OF 1 3/16-IN. SQ. BY 1-IN. BROACHES
For Hole 1 1/2 In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
G-1	0.868	0.900	9/16	0.843	0.875
G-2	0.900	0.940	9/16	0.875	0.915
G-3	0.940	0.988	5/8	0.915	0.963
G-4	0.988	1.045	11/16	0.963	1.020
G-5	1.045	1.107	3/4	1.020	1.082

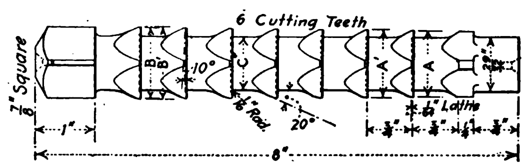


TABLE XIII.—DIMENSIONS OF 7/8-IN. SQ. BY 1 3/16-IN. BROACHES
For Hole 5 In. Long

No.	Lathe dimensions			Grinding dimensions	
	A' in.	*C'* in.	*C* in.	*A* in.	*B* in.
H-1	0.939	0.957	5/8	0.907	0.925
H-2	0.957	0.975	21/36	0.925	0.943
H-3	0.975	0.996	21/32	0.943	0.964
H-4	0.996	1.020	11/16	0.964	0.998
H-5	1.020	1.047	11/16	0.988	1.015
H-6	1.047	1.077	23/32	1.015	1.045
H-7	1.077	1.107	3/4	1.045	1.075
H-8	1.107	1.137	3/4	1.075	1.105
H-9	1.137	1.167	25/32	1.105	1.135
H-10	1.167	1.197	13/16	1.135	1.165
H-11	1.197	1.227	27/32	1.165	1.195

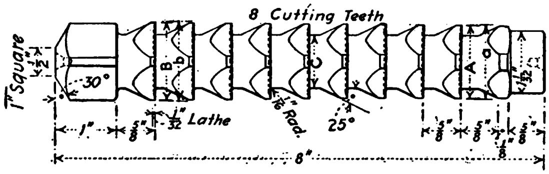


TABLE XIV.—DIMENSIONS OF 1-IN. SQ. BY 1¼-IN. BROACHES

For Hole 1½ In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
I-1	1.063	1.111	11/16	1.031	1.079
I-2	1.111	1.167	¾	1.079	1.135
I-3	1.167	1.231	13/16	1.135	1.199
I-4	1.231	1.302	⅞	1.199	1.270

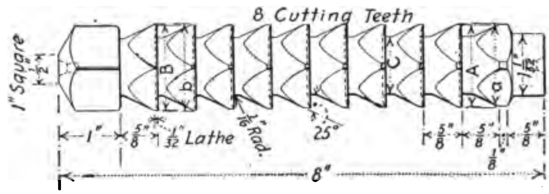


TABLE XV.—DIMENSIONS OF 1-IN. SQ. BY 1⅜-IN. BROACHES

For Hole 3½ In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
J-1	1.063	1.087	11/16	1.031	1.055
J-2	1.087	1.115	11/16	1.055	1.083
J-3	1.115	1.147	¾	1.083	1.115
J-4	1.147	1.183	¾	1.115	1.151
J-5	1.183	1.223	13/16	1.151	1.191
J-6	1.223	1.267	13/16	1.191	1.235
J-7	1.267	1.315	⅞	1.235	1.283
J-8	1.315	1.371	⅞	1.283	1.339
J-9	1.371	1.427	15/16	1.339	1.395

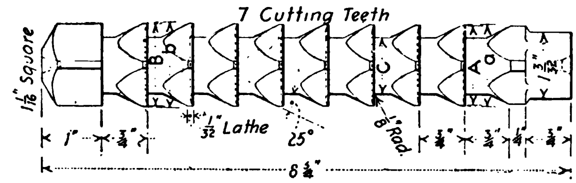


TABLE XVI.—DIMENSIONS OF 1 1/16-IN. SQ. BY 1 3/8-IN. BROACHES

For Hole 2 In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
K-1	1.122	1.142	3/4	1.090	1.110
K-2	1.142	1.169	3/4	1.110	1.137
K-3	1.169	1.202	13/16	1.137	1.170
K-4	1.202	1.242	13/16	1.170	1.210
K-5	1.242	1.282	7/8	1.210	1.250
K-6	1.282	1.322	7/8	1.250	1.290
K-7	1.322	1.362	15/16	1.290	1.330
K-8	1.362	1.392	15/16	1.330	1.360
K-9	1.392	1.412	15/16	1.360	1.380

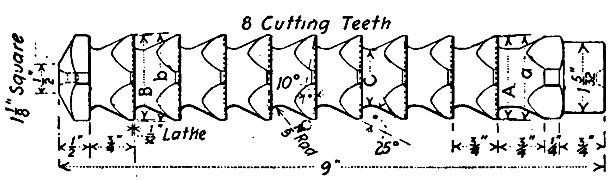


TABLE XVII.—DIMENSIONS OF 1 1/8-IN. SQ. BY 1 3/8-IN. BROACHES

For Hole 2 In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
L-1	1.188	1.212	25/32	1.156	1.180
L-2	1.212	1.240	13/16	1.180	1.208
L-3	1.240	1.276	13/16	1.208	1.244
L-4	1.276	1.320	7/8	1.244	1.288
L-5	1.320	1.372	15/16	1.288	1.340
L-6	1.372	1.427	15/16	1.340	1.395

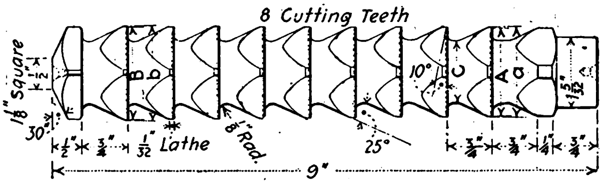


TABLE XVIII.—DIMENSIONS OF 1⅛-IN. SQ. BY 1½-IN. BROACHES
For Hole 4½ In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	b in.	c in.	A in.	B in.
M-1	1.187	1.211	13/16	1.155	1.179
M-2	1.211	1.239	13/16	1.179	1.207
M-3	1.239	1.271	27/32	1.207	1.239
M-4	1.271	1.307	⅞	1.239	1.275
M-5	1.307	1.347	⅞	1.275	1.315
M-6	1.347	1.391	15/16	1.315	1.359
M-7	1.391	1.439	1	1.359	1.407
M-8	1.439	1.493	1 1/32	1.407	1.461
M-9	1.493	1.553	1 1/32	1.461	1.521

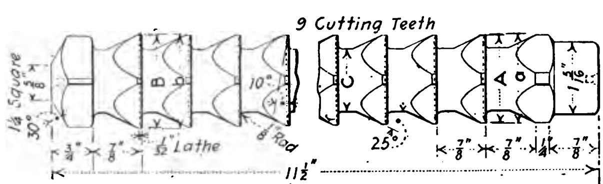


TABLE XIX.—DIMENSIONS OF 1¼-IN. SQ. BY 1⅝-IN. BROACHES
For Hole 2¼ In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	b in.	c in.	A in.	B in.
N-1	1.344	1.376	15/16	1.312	1.344
N-2	1.376	1.417	15/16	1.344	1.385
N-3	1.417	1.468	1	1.385	1.436
N-4	1.468	1.527	1	1.436	1.495
N-5	1.527	1.597	1 1/16	1.495	1.565
N-6	1.597	1.677	1⅛	1.565	1.645

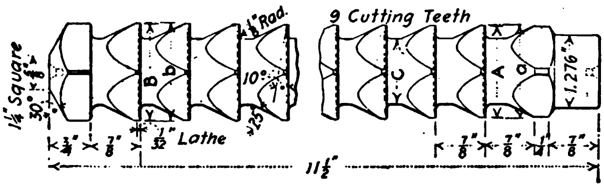


TABLE XX.—DIMENSIONS OF 1¼-IN. SQ. BY 1²³⁄₃₂-IN. BROACHES For Hole 4½ In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
O-1	1.313	1.344	15⁄16	1.281	1.312
O-2	1.344	1.375	15⁄16	1.312	1.343
O-3	1.375	1.411	15⁄16	1.343	1.379
O-4	1.411	1.452	1	1.379	1.420
O-5	1.452	1.497	1	1.420	1.465
O-6	1.497	1.549	1 1⁄16	1.465	1.517
O-7	1.549	1.607	1 1⁄16	1.517	1.575
O-8	1.607	1.679	1⅛	1.575	1.647
O-9	1.679	1.770	1 3⁄16	1.647	1.738

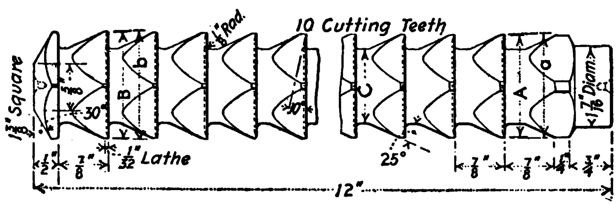


TABLE XXI.—DIMENSIONS OF 1⅜-IN. SQ. BY 1⅞-IN. BROACHES For Hole 4½ In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
Q-1	1.469	1.504	1	1.437	1.472
Q-2	1.504	1.544	1	1.472	1.512
Q-3	1.544	1.589	1 1⁄16	1.512	1.557
Q-4	1.589	1.639	1⅛	1.557	1.607
Q-5	1.639	1.697	1⅛	1.607	1.665
Q-6	1.697	1.762	1 3⁄16	1.665	1.730
Q-7	1.762	1.837	1¼	1.730	1.805
Q-8	1.837	1.927	1 5⁄16	1.805	1.895

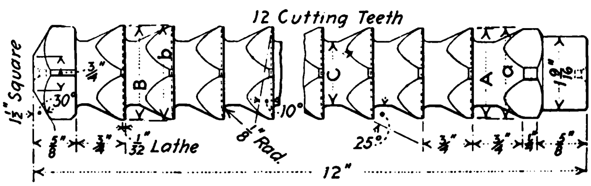


Table XXII.—Dimensions of 1½-in. Sq. by 2-in. Broaches
For Hole 3 In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
R-1	1.594	1.642	1 1/16	1.562	1.610
R-2	1.642	1.702	1 1/8	1.610	1.670
R-3	1.702	1.774	1 3/16	1.670	1.742
R-4	1.774	1.858	1 1/4	1.742	1.826
R-5	1.858	1.954	1 5/16	1.826	1.922
R-6	1.954	2.052	1 3/8	1.922	2.020

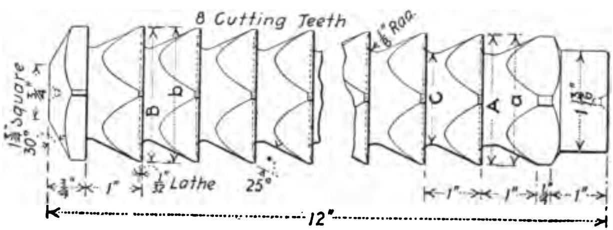


Table XXIII.—Dimensions of 1¾-in. Sq. by 2⅜-in. Broaches
For Hole 5 In. Long

No.	Lathe dimensions				Grinding dimensions	
	a in.	*b* in.	*c* in.	in.	*A* in.	*B* in.
U-1	1.842	1.860	1 3/16		1.812	1.830
U-2	1.860	1.882		1 3/16	1.830	1.852
U-3	1.882	1.909	1 1/4		1.852	1.879
U-4	1.909	1.940		1 1/4	1.879	1.910
U-5	1.940	1.976	1 5/16		1.910	1.946
U-6	1.976	2.016		1 5/16	1.946	1.986
U-7	2.016	2.061	1 3/8		1.986	2.031
U-8	2.061	2.110		1 3/8	2.031	2.080
U-9	2.110	2.164	1 7/16		2.080	2.134
U-10	2.164	2.222		1 7/16	2.134	2.192
U-11	2.222	2.285	1 1/2		2.192	2.255
U-12	2.285	2.353		1 5/8	2.255	2.323
U-13	2.353	2.425	1 5/8		2.323	2.395
U-14	2.425	2.470		1 5/8	2.395	2.440

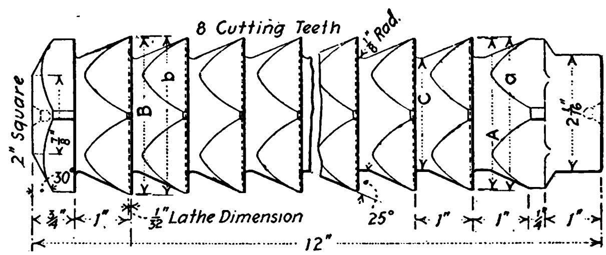


TABLE XXIV.—DIMENSIONS OF 2-IN. SQ. BY 2¾-IN. BROACHES

For Hole 6 In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
W-1	2.091	2.109	1 5/16	2.061	2.079
W-2	2.109	2.127	1 5/16	2.079	2.097
W-3	2.127	2.150	1⅜	2.097	2.120
W-4	2.150	2.173	1⅜	2.120	2.143
W-5	2.173	2.200	1 7/16	2.143	2.170
W-6	2.200	2.232	1 7/16	2.170	2.202
W-7	2.232	2.268	1½	2.202	2.238
W-8	2.268	2.308	1½	2.238	2.278
W-9	2.308	2.353	1 9/16	2.278	2.323
W-10	2.353	2.403	1 9/16	2.323	2.373
W-11	2.403	2.457	1⅝	2.373	2.427
W-12	2.457	2.516	1 11/16	2.427	2.486
W-13	2.516	2.579	1¾	2.486	2.549
W-14	2.579	2.645	1 13/16	2.549	2.615
W-15	2.645	2.717	1⅞	2.615	2.687
W-16	2.717	2.789	1 15/16	2.687	2.759

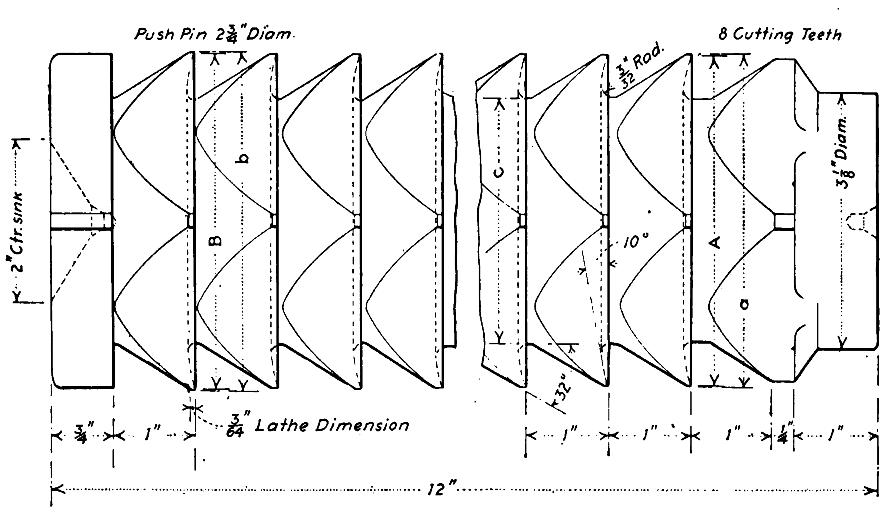


TABLE XXV.—DIMENSIONS OF 3-IN. SQ. BY 4⅛-IN. BROACHES
For Hole 9 In. Long

No.	Lathe dimensions			Grinding dimensions	
	a in.	*b* in.	*c* in.	*A* in.	*B* in.
Y-1	3.157	3.173	2⅜	3.125	3.141
Y-2	3.173	3.190	2⅜	3.141	3.159
Y-3	3.190	3.211	2⅜	3.159	3.179
Y-4	3.211	3.233	2⅜	3.179	3.201
Y-5	3.233	3.257	2 7/16	3.201	3.225
Y-6	3.257	3.283	2 7/16	3.225	3.251
Y-7	3.283	3.311	2 7/16	3.251	3.279
Y-8	3.311	3.341	2 7/16	3.279	3.309
Y-9	3.341	3.373	2½	3.309	3.341
Y-10	3.373	3.407	2½	3.341	3.375
Y-11	3.407	3.443	2½	3.375	3.411
Y-12	3.443	3.481	2½	3.411	3.449
Y-13	3.481	3.521	2 9/16	3.449	3.489
Y-14	3.521	3.565	2 9/16	3.489	3.533
Y-15	3.565	3.613	2⅝	3.533	3.581
Y-16	3.613	3.665	2⅝	3.581	3.633
Y-17	3.665	3.721	2⅝	3.633	3.689
Y-18	3.721	3.781	2 11/16	3.689	3.749
Y-19	3.781	3.845	2¾	3.749	3.813
Y-20	3.845	3.917	2 13/16	3.813	3.885
Y-21	3.917	3.997	2⅞	3.885	3.965
Y-22	3.997	3.055	2 15/16	3.965	4.053
Y-23	4.085	4.173	3	4.053	4.141

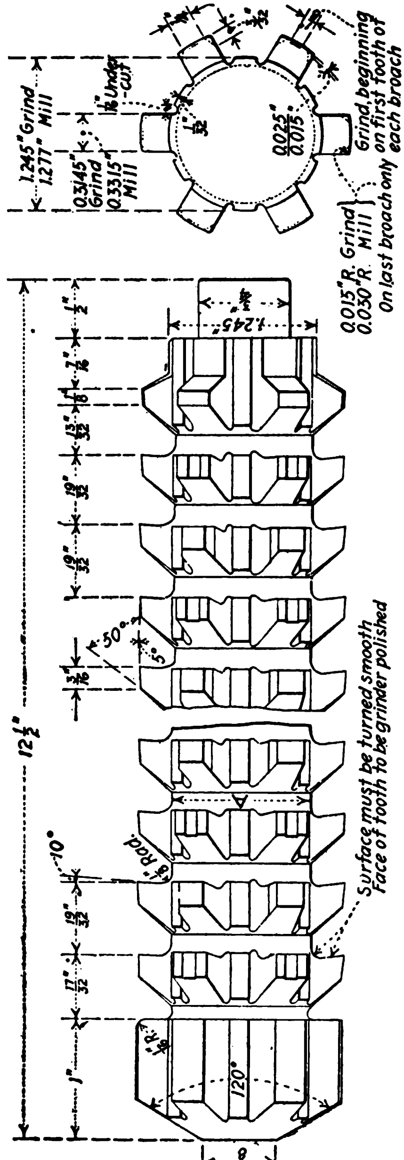

1.245" Grind
1.277" Mill
0.3145" Grind
0.3315" Mill
Grind beginning on first tooth of each broach
0.025"
0.015"
0.015" R. Grind
0.030" R. Mill
On last broach only
1.245"
12½"
50°
5°
10°
120°
Surface must be turned smooth
Face of tooth to be grinder polished

TABLE XXVI.—DIMENSIONS OF 1 1/4-IN. BY 1 23/32 SIX-SPLINE BROACHES
For Hole 4 1/2 In. Long

No.	Lathe dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
OA-1	1.282	1.286	1.290	1.294	1.298	1.302	1.306	1.310	1.315
OA-2	1.315	1.320	1.325	1.330	1.335	1.340	1.345	1.350	1.355
OA-3	1.355	1.360	1.365	1.370	1.375	1.380	1.385	1.390	1.395
OA-4	1.395	1.400	1.405	1.410	1.415	1.420	1.425	1.430	1.435
OA-5	1.435	1.440	1.445	1.450	1.455	1.460	1.465	1.470	1.475
OA-6	1.475	1.480	1.485	1.490	1.495	1.500	1.505	1.510	1.515
OA-7	1.515	1.520	1.525	1.530	1.535	1.540	1.545	1.550	1.555
OA-8	1.555	1.560	1.565	1.570	1.575	1.580	1.585	1.590	1.595
OA-9	1.595	1.600	1.605	1.610	1.615	1.620	1.625	1.630	1.635
OA-10	1.635	1.640	1.645	1.650	1.655	1.660	1.665	1.670	1.675
OA-11	1.657	1.680	1.685	1.690	1.695	1.700	1.705	1.710	1.715
OA-12	1.715	1.720	1.725	1.730	1.735	1.740	1.745	1.750	1.754

A	Grinding dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
13/16	1.250	1.254	1.258	1.262	1.266	1.270	1.274	1.278	1.288
27/32	1.283	1.288	1.293	1.298	1.303	1.308	1.313	1.318	1.323
7/8	1.323	1.328	1.333	1.338	1.343	1.348	1.353	1.358	1.363
15/16	1.363	1.368	1.373	1.378	1.383	1.388	1.393	1.398	1.403
31/32	1.403	1.408	1.413	1.418	1.423	1.428	1.433	1.438	1.443
1 1/32	1.443	1.448	1.453	1.458	1.463	1.468	1.473	1.478	1.483
1 1/16	1.483	1.488	1.493	1.498	1.503	1.508	1.513	1.518	1.523
1 3/32	1.523	1.528	1.533	1.538	1.543	1.548	1.553	1.558	1.563
1 1/8	1.563	1.568	1.573	1.578	1.583	1.588	1.593	1.598	1.603
1 5/32	1.603	1.608	1.613	1.618	1.623	1.628	1.633	1.638	1.643
1 5/32	1.643	1.648	1.653	1.658	1.663	1.668	1.673	1.678	1.683
1 5/32	1.683	1.688	1.693	1.698	1.703	1.708	1.713	1.718	1.722

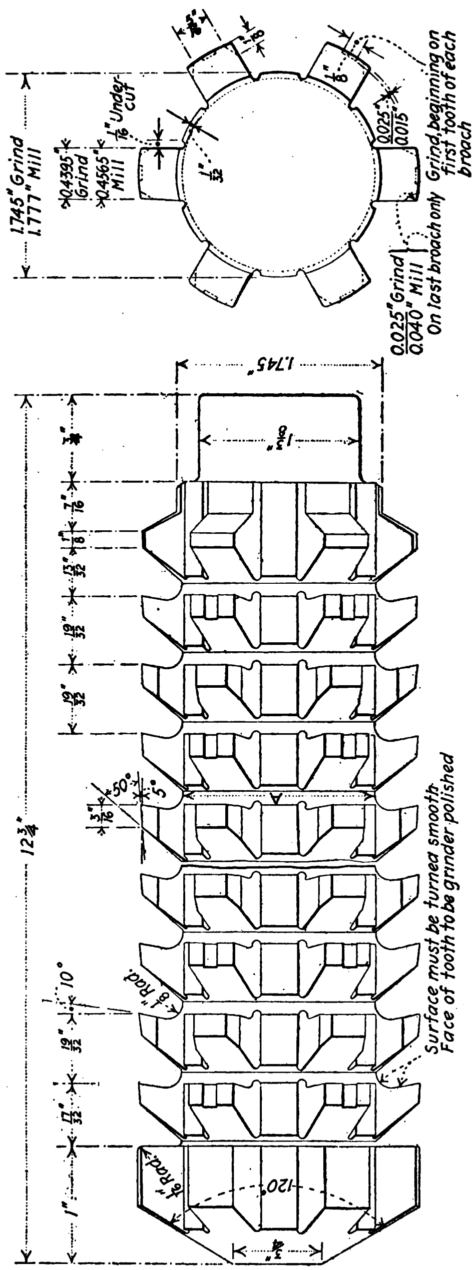

1.745" Grind
1.777" Mill
0.4395" Grind
0.4565" Mill
1/16" Under-cut
0.025"
0.015"
Grind beginning on first tooth of each broach
0.025" Grind
0.040" Mill
On last broach only
1.745"
12 3/4"
Surface must be turned smooth
Face of tooth to be grinder polished
120°
50°
5°
10°

Table XXVII.—Dimensions of 1 3/4 by 2 13/32-in., Six-spline Broaches For Hole 5 In. Long

No.	Lathe dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
UA-1	1.782	1.787	1.792	1.797	1.802	1.807	1.812	1.817	1.822
UA-2	1.822	1.827	1.832	1.837	1.842	1.847	1.852	1.857	1.862
UA-3	1.862	1.867	1.872	1.877	1.882	1.887	1.892	1.897	1.902
UA-4	1.902	1.907	1.912	1.917	1.922	1.927	1.932	1.937	1.942
UA-5	1.942	1.947	1.952	1.957	1.962	1.967	1.972	1.977	1.982
UA-6	1.982	1.987	1.992	1.997	2.002	2.007	2.012	2.017	2.022
UA-7	2.022	2.027	2.032	2.037	2.042	2.047	2.052	2.057	2.062
UA-8	2.062	2.067	2.072	2.077	2.082	2.087	2.092	2.097	2.102
UA 9	2.102	2.107	2.112	2.117	2.122	2.127	2.132	2.137	2.142
UA-10	2.142	2.147	2.152	2.157	2.162	2.167	2.172	2.177	2.182
UA-11	2.182	2.187	2.192	2.197	2.202	2.207	2.212	2.217	2.222
UA-12	2.222	2.227	2.232	2.237	2.242	2.247	2.252	2.257	2.262
UA-13	2.262	2.267	2.272	2.277	2.282	2.287	2.292	2.297	2.302
UA-14	2.302	2.307	2.312	2.317	2.322	2.327	2.333	2.339	2.345
UA-15	2.345	2.351	2.357	2.363	2.369	2.375	2.381	2.387	2.393
UA-16	2.393	2.399	2.405	2.411	2.417	2.423	2.429	2.435	2.441

A	Grinding dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
1 3/16	1.750	1.755	1.760	1.765	1.770	1.775	1.780	1.785	1.790
1 1/4	1.790	1.795	1.800	1.805	1.810	1.815	1.820	1.825	1.830
1 9/32	1.830	1.835	1.840	1.845	1.850	1.855	1.860	1.865	1.870
1 5/16	1.870	1.875	1.880	1.885	1.890	1.895	1.900	1.905	1.910
1 11/32	1.910	1.915	1.920	1.925	1.930	1.935	1.940	1.945	1.950
1 13/32	1.950	1.955	1.960	1.965	1.970	1.975	1.980	1.985	1.990
1 7/16	1.990	1.995	2.000	2.005	2.010	2.015	2.020	2.025	2.030
1 15/32	2.030	2.035	2.040	2.045	2.050	2.055	2.060	2.065	2.070
1 17/32	2.070	2.075	2.080	2.085	2.090	2.095	2.100	2.105	2.110
1 9/32	2.110	2.115	2.120	2.125	2.130	2.135	2.140	2.145	2.150
1 19/32	2.150	2.155	2.160	2.165	2.170	2.175	2.180	2.185	2.190
1 5/8	2.190	2.195	2,200	2.205	2.210	2.215	2.220	2.225	2.230
1 21/32	2.230	2.235	2.240	2.245	2.250	2.255	2.260	2.265	2.270
1 21/32	2.270	2.275	2.280	2.285	2.290	2.295	2.301	2.307	2.313
1 21/32	2.313	2.319	2.325	2.331	2.337	2.343	2.349	2.355	2.361
1 21/32	2.361	2.367	2.373	2.379	2.385	2.391	2.397	2.403	2.409

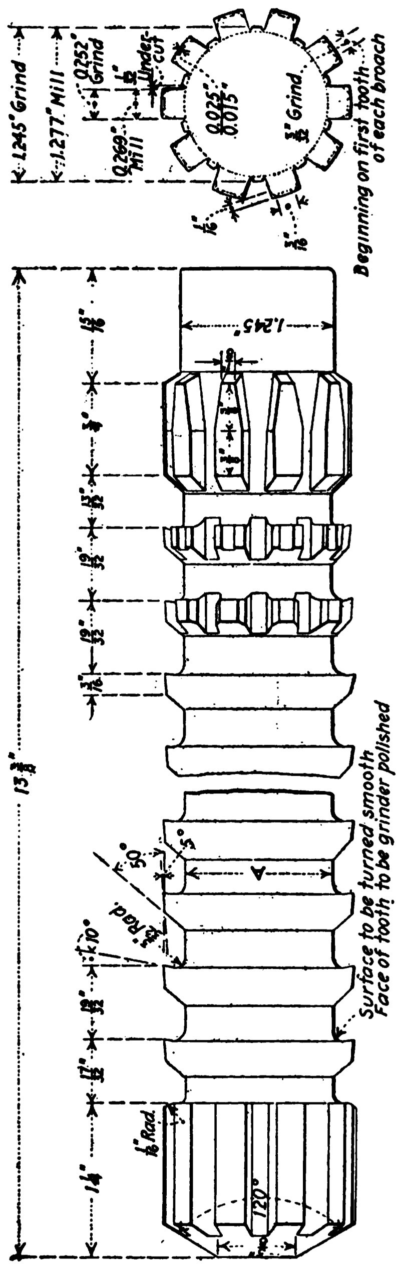

1.245" Grind
1.277" Mill
0.252" Grind
0.269" Mill
Under-cut
0.025"
0.015"
Grind
Beginning on first tooth of each broach
1.245"
13"
Surface to be turned smooth
Face of tooth to be grinder polished
Rad.
50°
5°
10°
A
120°

TABLE XXVIII.—DIMENSIONS OF 1¼ BY 1³⁵⁄₆₄-IN., TEN-SPLINE BROACHES
For Hole 4½ In. Long

No.	Lathe dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
OA-1	1.282	1.287	1.292	1.298	1.303	1.309	1.314	1.319	1.325
OA 2	1.325	1.330	1.336	1.341	1.346	1.352	1.357	1.363	1.368
OA-3	1.368	1.373	1.379	1.384	1.390	1.395	1.400	1.406	1.411
OA-4	1.411	1.417	1.422	1.427	1.433	1.438	1.444	1.449	1.454
OA-5	1.454	1.460	1.465	1.471	1.476	1.481	1.487	1.492	1.498
OA-6	1.498	1.503	1.508	1.514	1.519	1.525	1.530	1.535	1.541
OA 7	1.541	1.546	1.552	1.557	1.562	1.568	1.573	1.579	1.585

A	Grinding dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
29⁄32	1.250	1.255	1.260	1.266	1.271	1.277	1.282	1.287	1.293
15⁄16	1.293	1.298	1.304	1.309	1.314	1.320	1.325	1.331	1.336
31⁄32	1.336	1.341	1.347	1.352	1.358	1.363	1.368	1.374	1.379
1	1.379	1.385	1.390	1.395	1.401	1.406	1.412	1.417	1.422
1 1⁄16	1.422	1.428	1.433	1.439	1.444	1.449	1.455	1.460	1.466
1 3⁄32	1.466	1.471	1.476	1.482	1.487	1.493	1.498	1.503	1.509
1⅛	1.509	1.514	1.520	1.525	1.530	1.536	1.541	1.547	1.553

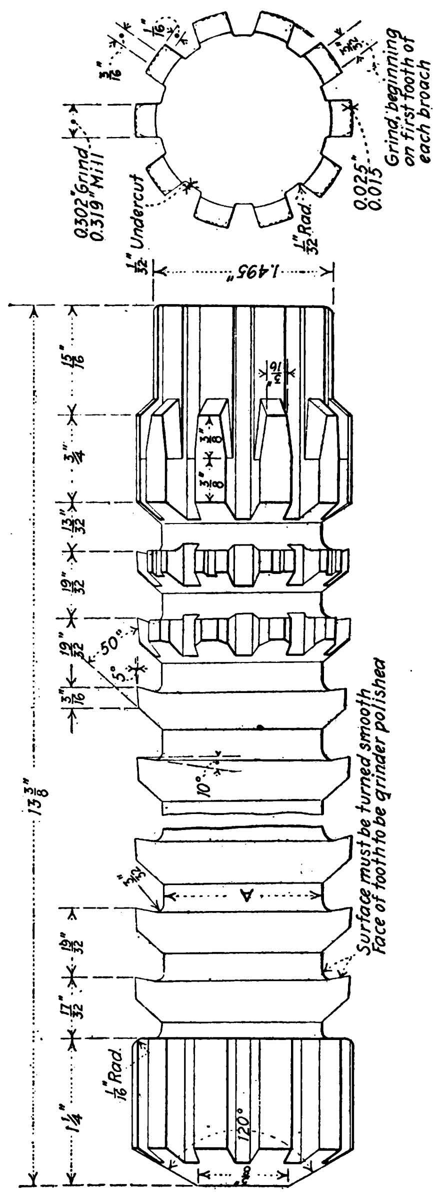

0.302" Grind
0.319" Mill
Undercut
Rad.
0.025"
0.015"
Grind, beginning on first tooth of each broach
1.495"
Surface must be turned smooth
Face of tooth to be grinder polished
A
50°
5°
10°
120°

Table XXIX.—Dimensions of 1½ by 1 55/64-in., Ten-spline Broaches For Hole 4½ In. Long

No.	Lathe dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
SA-1	1.532	1.537	1.542	1.547	1.552	1.557	1.562	1.567	1.572
SA-2	1.572	1.577	1.582	1.587	1.592	1.597	1.602	1.607	1.612
SA-3	1.612	1.617	1.622	1.627	1.632	1.637	1.642	1.647	1.652
SA-4	1.652	1.657	1.662	1.667	1.672	1.677	1.682	1.687	1.692
SA-5	1.692	1.697	1.702	1.707	1.712	1.717	1.722	1.727	1.732
SA-6	1.732	1.737	1.742	1.747	1.752	1.757	1.762	1.767	1.772
SA-7	1.772	1.777	1.782	1.787	1.792	1.797	1.802	1.807	1.812
SA-8	1.812	1.817	1.822	1.827	1.832	1.837	1.842	1.847	1.852
SA-9	1.852	1.857	1.862	1.868	1.873	1.878	1.883	1.888	1.894

A	Grinding dimensions								
	1st tooth	2 & 3	4 & 5	6 & 7	8 & 9	10 & 11	12 & 13	14 & 15	16 & 17
1 1/16	1.600	1.505	1.510	1.515	1.520	1.525	1.503	1.535	1.540
1 3/32	1.540	1.545	1.550	1.555	1.560	1.565	1.570	1.575	1.580
1 5/32	1.580	1.585	1.590	1.595	1.600	1.605	1.610	1.615	1.620
1 3/16	1.620	1.625	1.630	1.635	1.640	1.645	1.650	1.655	1.660
1 7/32	1.660	1.665	1.670	1.675	1.680	1.685	1.690	1.695	1.700
1¼	1.700	1.705	1.710	1.715	1.720	1.725	1.730	1.735	1.740
1 9/32	1.740	1.745	1.750	1.755	1.760	1.765	1.770	1.775	1.780
1 11/32	1.780	1.785	1.790	1.795	1.800	1.805	1.810	1.815	1.820
1⅜	1.820	1.825	1.830	1.836	1.841	1.846	1.851	1.856	1.860

SQUARING THE HOLES IN UNIVERSAL JOINT FORKS

Blood Bros., Kalamazoo, Mich., make universal joint forks out of a particularly tough steel. The holes are first rough-squared in a keyseater

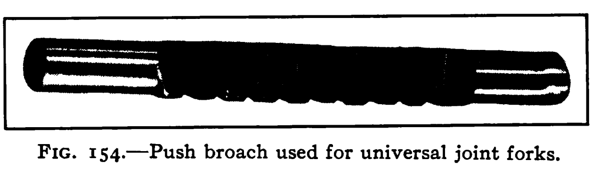


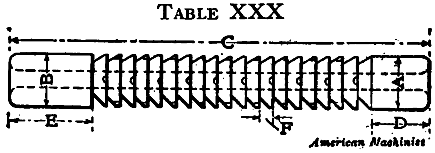
Fig. 154.—Push broach used for universal joint forks.

to within a few thousandths of the finish size, then a broach is forced through in a hydraulic press, enough of the original round hole being left to act as a guide to the pilot on the broach, which when used on this class of material, in this way, has a tendency to twist or crowd over to one side. The type of broach used, which is shown in Fig. 154 is about 14 in. in length, with a 2½- or 3-in. pilot and a 2-in. shank. The teeth are of ½-in. pitch and increase in size by 0.001 in. up to the last tooth which is full size and twice as wide as the others. The face of the teeth are ground perfectly straight and parallel with the center line of the tool, giving absolutely no clearance, though the cutting edge is slightly hooked to give a curling chip. By giving the teeth no outside clearance the company claims that the tendency to creep is minimized.

SIZES FOR BABBITTED BEARINGS

Table XXX compiled by Geo. Hey, gives the sizes used for broaching out solid and split babbitted bearings, the split ones being clamped together in pairs. He says it takes no longer to broach out a bearing than it does to carry it to a lathe. Only one broach was used up to the 3-in. sizes, but above that two were used. About 0.002 in. oversize was allowed on each broach for the spring of the metal.

Table XXX



Size	A	B	C	D	E	F	Size.	A	B	C	D	E	F
3/4"	0 735"	0 752"	6"	1"	1 1/2"	1/8"	2 1/2"	2.488"	2 502"	12"	2"	1"	3/8"
7/8"	0 860"	0 877"	6"	1"	1 1/2"	1/8"	2 3/4"	2.739"	2 752"	12"	2"	4"	3/8"
1"	0.986"	1 002"	8"	1 1/4"	1 1/2"	1/8"	3"	2.964" 2.996"	2.998" 3 002"	12"	2"	4"	3/8"
1 1/8"	1 112"	1 127"	8"	1 1/4"	1 1/2"	3/16"	3 1/4"	3.233" 3 246"	3.249" 3.252"	14"	2"	4"	1/2"
1 1/4"	1 236"	1 252"	8"	1 1/4"	1 1/2"	3/16"	3 1/2"	3 486" 3 496"	3.498" 3 502"	14"	2"	4"	1/2"
1 3/8"	1 364"	1 377"	8"	1 1/4"	1 1/2"	3/16"	3 3/4"	3 736" 3 746"	3 748" 3.752"	14"	2"	4"	1/2"
1 1/2"	1 488"	1 502"	10"	1 1/2"	1 3/4"	1/4"	4"	3 985" 3 996"	3 998" 4 002"	14"	2"	4"	5/8"
1 3/4"	1 739"	1 752"	10"	1 1/2"	1 3/4"	1/4"	4 1/4"	4 236" 4 246"	4 248" 4 252"	14"	2"	4"	5/8"
2"	1 970"	2 002"	10"	1 1/2"	1 3/4"	1/4"	4 1/2"	4 486" 4.496"	4 498" 4.502"	14"	2 1/2"	4"	5/8"
2 1/4"	2 236"	2 252"	10"	1 1/2"	1 3/4"	3/8"							

BROACHES FOR BRONZE OR BABBITT

In writing of some of the work done in the shops of the Westinghouse Electric & Manufacturing Co., C. B. Auel says in part:

Practically all our babbitted railway, mine, crane and industrial-motor bearings up to 4½ in. and even 5 in. diameter, when made either to standard bores, or if special, in sufficiently large quantities, now have a broaching operation performed upon them. Over these diameters, the cost of the broach becomes too expensive for the quantities ordinarily involved and such bearings are generally machined in the usual way. The broaching operation may be either a "rough" or a "finish" one, or it may include both. The operation of rough broaching simply roughs out the bore, a subsequent operation either by a further broaching or by boring being necessary to complete this part of the bearing; this second operation is termed "finish" boring.

A one-piece babbitted cast-iron armature bearing (2½ by 6 in.) for a light street-car motor, and a similar but larger babbitted-bronze bearing (3 by 7½ in.) for a heavier railway motor are regularly broached. In the babbitting of one-piece bearings, if the oil grooves are to be cut in afterward instead of being cast in with the babbitt, the babbitting mandrel may consist of a plain round bar, slightly tapered, to permit of its being withdrawn from the mold after the babbitt has been poured. In bearings, however, where the oil grooves are cast in, collapsible mandrels of various types are generally used. The mandrels are made from 0.004 to 0.020 in. smaller in diameter than the finished bearings, leaving this amount of babbitt plus the clearance allowance to be removed by the broach.

After babbitting, the mandrel and plugs are removed, the fins and any surplus babbitt penetrating the cored holes are burned away with a hot soldering iron, the oil grooves are finished off and the bearing broached in a hydraulic press. A pressure of 5 to 10 tons is required, depending upon the diameter and the length of the bearing, as well as upon the hardness of the metal and the amount removed. The actual time of broaching is very small, in general varying from 1 to 2 min. The bearing is next placed upon an arbor, turned and faced in a lathe, after which it is either profiled on the outside for a keyway or similarly drilled for a dowel pin when it is then completed. It is sometimes necessary, especially when the oil grooves are cut in the lining after babbitting, to run the broach through the bearing a second time in order to remove any slight roughness from the edges of the oil grooves.

Broach Details

A reproduction of a standard broach used for bearings, whether babbitted or of bronze, is detailed in Fig. 155, and in Fig. 156 is illustrated a group of such broaches. It is to be noted in the detailed broach that while it is for a bearing to accommodate a shaft of 1½-in. diameter, the maximum diameter is 0.005 in. in excess of this dimension, the difference allowing for the running fit required and for any slight "come back" in the babbitt after broaching. Experience seems to indicate that there is a tendency for the babbitt to expand very gradually after broaching, so that a bearing which has been allowed to stand for several months will sometimes show a slightly reduced diameter and this tendency must be allowed for in the broach.

It will be noticed further, that among the group of broaches shown, are some in which the cutting edge is a continuous spiral, while in others the cutting is done by a series of circular edges entirely independent of one another. As far as the actual cutting is concerned, there is no difference between the two types, but in the matter of keeping the broach free from chips, the spiral design is to be preferred.

Unsatisfactory Forms For Broaching

In bearings of the type shown in Fig. 157 whether of cast or malleable iron or of bronze, the design is such that broaching alone is insufficient to give a perfect hole, and such bearings while they may be rough-broached, should in general be finish-bored, if the very best results are to be obtained. This is on account of the great amount of metal omitted on one side, due to the large oil hole, which causes the broach when being driven through, to do little or no cutting on the side opposite. There is, however, a way in which this tendency may frequently be overcome and that is by filling the oil hole with babbitt and inclosing the bearing in a suitable pot while broaching, the babbitt being burned out afterward. The broach is thus supported all around, and is enabled to cut a clean hole and one concentric with the circumference of the bearing.

Experience With Two-piece Bearings

Considerable difficulty was encountered when broaching two-piece bearings was first undertaken, and various experiments were made without attaining any pronounced success. The half bearings were milled along the edges, then fitted together, faced, counterbored and babbitted. The complete bearing was next set within a forged ring around the circumference of which, and projecting inwardly, were placed setscrews which could be set tightly against the bearing, thus securing it firmly in a central position, the idea being to have one such ring take in a number of sizes. Upon driving home the broach, the halves separated slightly, due to an almost imperceptible springiness in the several parts, sufficient however, to prevent any really satisfactory results. Modifications of this method showed that the best way to do the work was to surround them with a snugly fitting ring made for but one kind of bearing, and of size and strength enough to prevent all distortion. Our procedure now is to rough-broach them in this kind of a ring, then remove them and clamp them onto a mandrel and finish the outside, after which they are again placed in another close-fitting ring and finish-broached. Owing to the fact that the first ring used holds the rough casting, it is provided with short, heavy setscrews, but the last one used is bored so that the bearing is a snug fit.

PUSH BROACHES FOR A VARIETY OF WORK

The *American Machinist* published an article by S. E. Summers, manager of the Detroit shops of the Chicago Pneumatic Tool Co., on the use of push broaches in the finishing of some of the parts of their air hammers and other tools, which is reproduced herewith, as it contains much valuable information on that class of work.

In presenting this article it is not my intention to convey the idea that the method shown is the modern way of broaching, but simply to give the

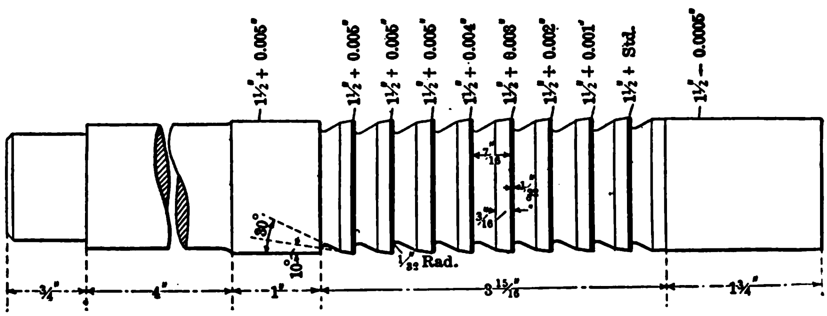


FIG. 155.—Detail broach for bearing.

FIG. 156.—Group of broaches for bearings.

FIG. 157.—A difficult bearing to broach.

benefit of our experience, and this will serve to show what can be accomplished on a standard broaching press, which, when not in use for broaching, is busy on the many assembling operations which can only be handled on a press of this nature.

Broaches for Hexagon Holes

The halftone, Fig. 158, showing a portion of the press with broaches in place, will illustrate the method used in broaching the hexagon hole in our pneumatic-hammer chisel bushing, Fig. 159, the material of which is a high-grade carbon steel. The length of the piece is 7/8 in. and the hole measures 19/32 in. across the flats. We use four broaches simultaneously and at each stroke of the ram we complete one piece. The hole in the blank is bored to 19/32 in. and the guide on the broaches is made 0.003 in. under this size. The follower on the upper end of the broach is made long enough to allow the broach to drop through the work when the ram is at the end of the stroke. The broaches, Fig. 160, are 6 in. long overall and have 14 teeth with 1/4-in. pitch. The first six teeth advance 0.010 in. each or 0.005 in. on each side, as the first few teeth only cut on the corners as in Fig. 161, and no trouble is experienced, but as the cut becomes heavier it must necessarily be reduced, depending on the nature of the material and length of the cut. In this case we find that the teeth can be advanced 0.003 in. with full cut or 0.0015 in. on each side. I know of no rule that can be safely followed for the amount of cut to allow.

The first tooth on broach No. 2 is made the same size as the last tooth on No. 1 to assist in centering, and so on with Nos. 3 and 4. The last six teeth on the finishing broach No. 4 are made parallel to insure the size holding up to standard.

In the making of the broaches the blanks are turned and milled allowing a light cut for finishing. They are then carefully annealed, grooved and the teeth are finished with an end mill to give 2 deg. clearance. There is practically no hand work required to finish them except to give a little retouching. If a little care is taken in handling and annealing no trouble will be experienced in tempering and they will be quite straight. There will be no trouble from the chips wedging in the grooves if they are properly formed and a little experience will determine what that is, depending entirely on the nature of the work, bearing in mind that all broaches must have plenty of chip room; if not there will be trouble from the teeth breaking.

Broaches for Square Holes

The broaches, Fig. 162, for the square hole in the piece, Fig. 163, are made practically the same as for hexagon holes. They are 10 1/4 in. long overall, the teeth are of 5/16-in. pitch and the hole when finished is 5/8 in. across the flats. The teeth advance 0.003 in. each or 0.0015 in. on a side. Three broaches are required for this piece with the work divided as in Fig. 164. In this case we drill the hole in the blank 21/32 in. as we do not require a perfect square.

FIG. 158.—Broaching press.

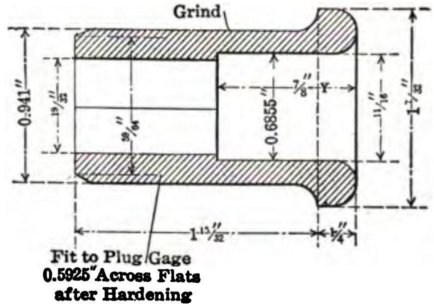


FIG. 159.—Section through bushing with hexagonal hole.

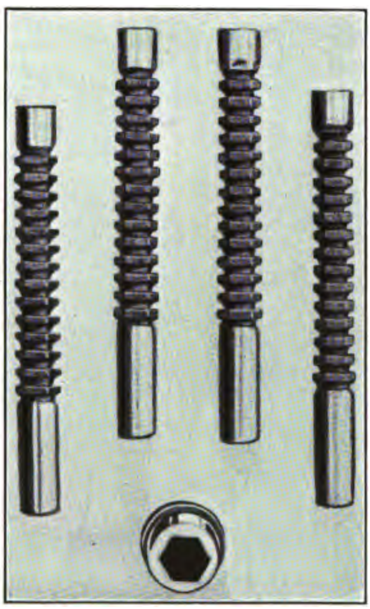


FIG. 160.—Broaches for hexagonal hole.

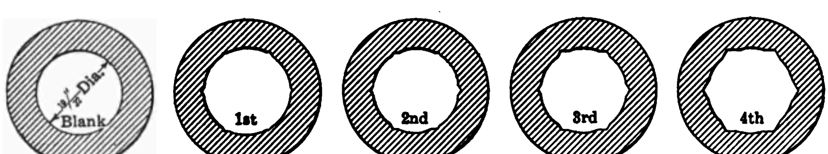


FIG. 161.—Sequence of operations in broaching the hexagonal hole.

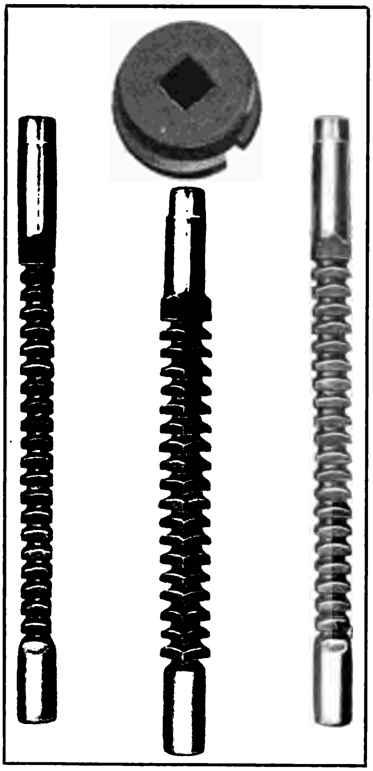


FIG. 162.—Broaches for a square hole.

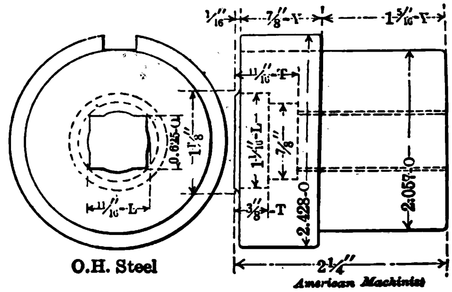


FIG. 163.—Piece with square-broached hole.

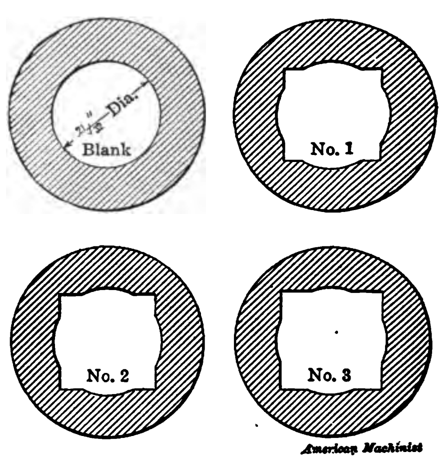


FIG. 164.—Steps in broaching a square hole.

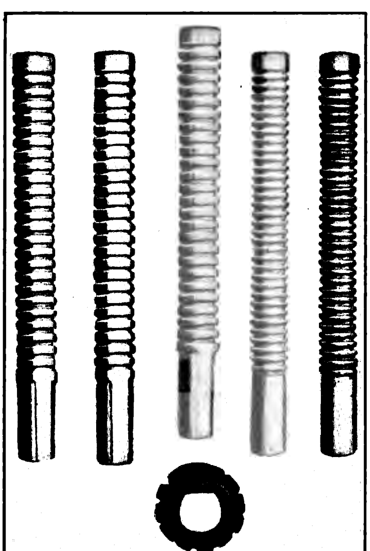


FIG. 165.—Another set of broaches.

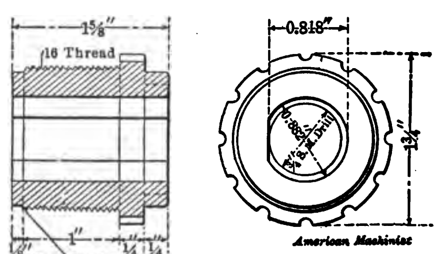


FIG. 166.—Piece broached with the tools in Fig. 165.

BROACHES FOR ROUND HOLES WITH FLAT SIDES

From Fig. 165, it will no doubt be seen that trouble was experienced with the next piece. This is shown also in Fig. 166, and is one of the most difficult pieces we have ever had to broach. It is of tool steel and is 1⅝ in. long, bored to ⅝ in. diameter, and is broached to ¾ in. leaving one side flat, the face being 5/16 in. from center. The same method was used in making the broaches as for the others, except that they were ground all over after tempering, by which method we are able to have them perfectly straight. The three broaches with heavy teeth are practically new and found by experience to be a better design. The teeth advance 0.001 in. each or 0.0005

FIG. 167.—Broaches for internal gears.

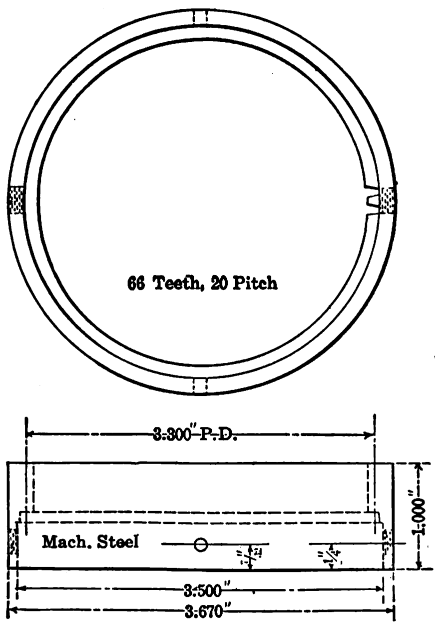


FIG. 168.—Internal gear to be broached.

in. on each side; they are of ¼-in. pitch and the broaches are 8½ in. long overall. They also have longitudinal grooves to break the chips which is quite important in this case.

BROACHES FOR INTERNAL GEARS

The broaches shown in Fig. 167 are extensively used on small internal gears, of which we have a great many of various sizes, one of which is seen in Fig. 168. They may look to the reader like very difficult broaches to make, but are comparatively simple. They are 8⅜ in. long overall, with a 1-in. hole running through, cleared in the center allowing ¾-in. bearing at each end.

After roughing out the blanks they were annealed to remove strains, the grooves being then cut in the lathe and the teeth milled straight, practically the same as though making a long gear, as we have found by experience that no clearance is required. They are then tempered and ground in the groove to bring the cutting edge up sharp. The cutting is all done on the points of the teeth and the outside diameters of the teeth advance 0.006 in. each, leaving the last three teeth straight to insure the size being accurate. The cutting teeth are spaced 3/8 in. between centers. The gear being broached has a 1/2-in. face and 66 teeth of 20 diametral pitch. The blank is roughed out 1/32 in. large outside diameter and is held in a collar while being broached to prevent spreading, after which it is mounted on a special fixture and centered from the teeth while being finished on the outside to insure the outside diameter being true with the teeth. This work is all handled in our Watson-Stillman broaching press, using lard oil as a lubricant.

A BUILT-UP INTERNAL-GEAR BROACH

The following description of a built-up broach, made by a correspondent of the *American Machinist* for cutting internal gears, is interesting, though he admits that two broaches would have given a more satisfactory job, had the expense not been so great. However, he says, as the job did not require the greatest accuracy, this being a case of quantity in as short a time as possible, it was decided to make one broach do.

The broach was made of tool-steel disks, turned to the sizes given in Fig. 169, held together with a crucible-steel binding-bolt not hardened, as we were afraid it would warp. This was very important as we depended on the key, which was hardened and ground, to bring the teeth in line. The disks were turned in the usual manner, allowance being made for grinding on the flats. The keyway was then put in to gage. The teeth were cut on a mandrel with a taper shank to fit the dividing head, and a key to fit the cutter, so the teeth could be located uniformly from the key. These teeth were cut about 1/2 deg. taper for clearance. It was only necessary to set the cutter once for the entire lot of disks, as the bottoms of the teeth were all alike. After the disks were hardened, they were ground and assembled. The teeth were not perfectly in line, but were commercially good enough.

These broaches were used in a Watson-Stillman hydraulic press, and our first trouble was in the tearing of the metal on the bottom side as the teeth cut through, as the forgings were very tough. This was partially overcome by leaving a small amount to counterbore afterward, and by using the best grade of lard oil as a lubricant. The next trouble was in the tendency of the broach to creep to one side, making the teeth cut out of truth with the outside of the gear. The remedy for this was to leave enough on the outside to finish after the gear teeth were broached. From 200 to 225 of these gears were broached in 10 hr. with this tool.

Another writer, commenting on the foregoing, says that he would make the broach a solid piece of tool steel as shown in Fig. 170 large enough to turn to the outside of the gear teeth, in this case 3.116 in., and without any

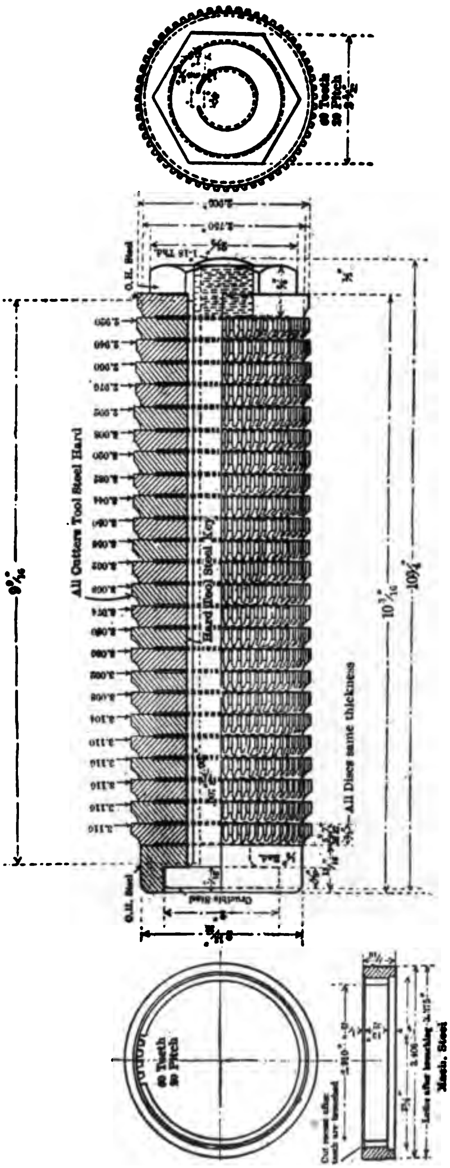


FIG. 169.—A built-up internal-gear broach.

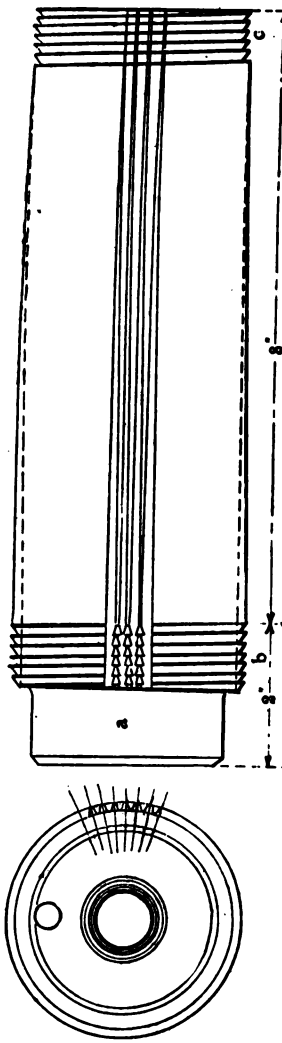


FIG. 170.—A one-piece gear broach.

calculation beyond a desire for good proportion, 10 in. in length. This should be centered and a shank, 1 in. long and 2½ in. in diameter turned on one end at *a*. Then the piece should be strapped to a face-plate, with the turned end in the steady-rest, and a hole drilled and tapped in the end, with a 1-in. pipe tap, and the edge of the hole trued up for a center. This is used to screw in a piece of 1-in. pipe to handle the broach with when hardening and tempering. Next the blank is put between centers and turned for about 1 in. at *b*, next to the shank already turned, for a space about 1 in. wide and to the diameter of the gear. The other end *c* is then turned to the diameter of the root of the teeth for a little distance. The tailstock is now set over to turn a taper from *c* to *d*. Then while the lathe is adjusted to the taper, cut a ratchet thread, eight to the inch, the entire length of the taper. After setting the tailstock back, the 1-in. strip *b* is threaded, making eight full-sized threads. It is now ready for the teeth, which are cut parallel, the cutter just touching at the small end, and going full depth at the other. The formula $\frac{2.157}{P}$ for the full depth of the tooth shows this to be 0.1078 and as there are 8 in. of taper and eight threads per inch, each tooth will have a little less than 0.0017 in. to cut, which is just a nice chip. When the teeth are all cut, if the cutter is kept sharp so there are no burrs, the broach is ready to harden without any kind of hand work being done on it.

A little spring in the hardening makes no difference, as the final sizing is done by the last eight teeth, which are too short to spring, and as the bottoms of the teeth are the same size as the hole in the gear blank, it serves as a guide and prevents creeping.

EXPANDING HOLLOW CYLINDERS

In the *American Machinist* A. D. Hallett explains how to expand under-sized bushings as follows:

In Fig. 171 is shown a button broach that is cheap to make and the life of which is practically endless when used on metal that has not been hardened. Added to this, it leaves a mirrorlike finish in the drifted hole when lubricated with a heavy oil.

I have made a large number of these broaches, using about 110-point carbon steel and allowing nothing for a grind; but after hardening they were polished with emery cloth. In machining a gradual increase of 0.002 in. to the button was used, while the ends *A* and *B* were left 0.005 in. under the diameter of the hole to be expanded. By making these broaches in progressive sizes the limit of expansion of any metal can be reached and many otherwise spoiled pieces reclaimed.

A PAIR OF PECULIAR BROACHES

In the Jan. 1, 1903, issue of the *American Machinist*, J. L. Lucas wrote:

In Fig. 172 is shown a pair of broaches, used for squaring round holes on Locomobile wheel hubs, that for efficiency and ingenuity go ahead of anything that I have seen yet. I say ingenuity, for, while all our broaches are made with this style of tooth, this is the smallest size we use, and it did not leave strength enough to cut the teeth on all four sides in the regular manner, so the idea of broaching one-half of the hole at a time is where the ingenuity came in. The first broach is made with teeth on two sides only, and the other side or back is left round and of the same

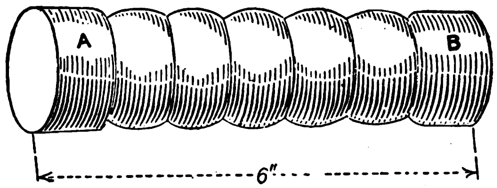


FIG. 171.—Button broach.

diameter as the leading hole through the hub. No. 2 also is cut with teeth on two sides, and the back is made rectangular, fitting the half of the square that has already

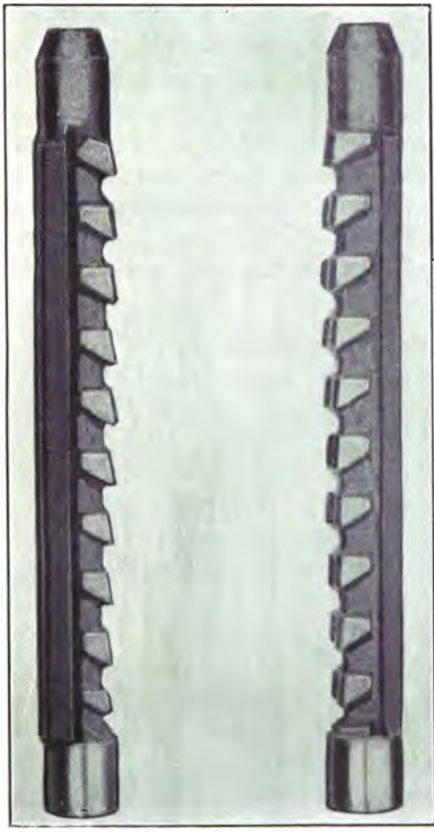


FIG. 172.—A pair of peculiar broaches.

FIG. 173.—A diamond-toothed broach.

been broached by No. 1. The result is a nice square hole produced at two strokes, one stroke of each broach, and the work is done equally well in iron, steel or bronze, and comes central with the rest of the hub, a very important feature in the work they are used upon. This style of tooth is used in all our broaches and never clogs or tears out the metal, and takes less power than the old-style shearing cut broach. It was designed and made by the foreman in our tool room, Mr. E. H. Metcalf.

A DIAMOND-TOOTHED BROACH

A number of years ago the General Electric Co., West Lynn. Mass., used the diamond-toothed broach shown in Fig. 173 to broach out round holes in steel castings. The teeth are backed off slightly and the broach is used in a mandrel press, about 0.01 in. of metal being removed with comparatively little pressure. In order to not leave a line in the work the spirals are cut with one less flute on the right than on the left.

POWER REQUIRED TO BROACH STEEL

From data obtained from Mr. Spicer, the power required to force various push broaches through work in a 20-ton hydraulic press, is as follows: 1⅜-in. leader broach, for 1 13/32-in. round hole, 150 to 170 lb. per sq. in., 1⅜, six-spline broach, 90 to 110 lb.; 5/16-in. keyway broach, 5 to 15 lb.; 1¼ square broach, 70 to 90 lb.; 1¼ square broach, finish size, 35 to 45 lb.

The pressure required for 20 tons in this press is about 225 lb., so that the ton pressure required for the broaches named can be easily calculated. The high pressure required for the round leader broach is accounted for by the fact that it cuts entirely around the hole.

CHAPTER VII

MAKING BROACHES

There are numerous ways of making broaches, when it comes to the actual machining processes. A large factor in the methods used will of course be the shop equipment at hand. As a general rule it is far better to have broaches made by firms making a specialty of such work rather than for inexperienced men to try it. At the present time broaches for keyways, round, square and certain classes of multispline holes, may be purchased almost as readily as are the regular run of drills or reamers, since the types of broaches referred to are carried in stock ready for quick shipment. However, some firms prefer to do their own work, others have to meet special conditions which compel them to manufacture their own tools. For this reason the following descriptions of actual shop practice will be of interest, and will serve as a general guide for machining, hardening, grinding and straightening of broaches of various types.

PULL-BROACH WORK

On the shop methods for machining pull broaches, E. A. Suverkrop, one of the editors of the *American Machinist*, has been of immense assistance in gathering the data and the photographs needed to make plain the text. A large part of the material gathered by him was obtained in the shop of the J. N. Lapointe Co., New London, Conn., who besides building a line of belt- and motor-driven broaching machines manufacture an extensive line of broaches, many of which, for standard work, are kept in stock.

Broaches are made of four kinds of steel: Mild steel, case-hardened; carbon steel; alloy steel and high-speed steel. Carbon steel is the material most commonly used for medium and large-size broaches and for fine-finishing cuts. For small broaches tough alloy steel containing vanadium is used. High-speed steel is used for finishing broaches in hard material.

The life of a broach is difficult to determine, depending as it does on so many conditions. A certain carbon steel broach finished 28,000 holes 1 in. square in machinery steel 1¾ in. thick.

Another broach, made of Colonial Special steel, broached 12,000 automatic pistol frames with two grindings.

TURNING LONG, SLENDER BROACHES

Owing to the small diameter of broaches as compared to their length, considerable trouble from springing and chattering is likely to be encountered while turning the blanks. Follower rests of the usual type are of no use as the work is tapered. A simple self-adjusting follower rest is shown in Fig. 174 at *A*. It consists of a piece of wood with a notch in it to fit over the work. Two nails are driven in the wood, one near each end. Over these are hung pieces of iron with holes in them. The back end of the wood rests on the back of the carriage. The amount and location of the weights *B* is obtained by trial. Sometimes the heavier weight is placed on the lower nail and sometimes on the upper one. While crude, this follower rest is entirely satisfactory and may be of use for turning other slender work.

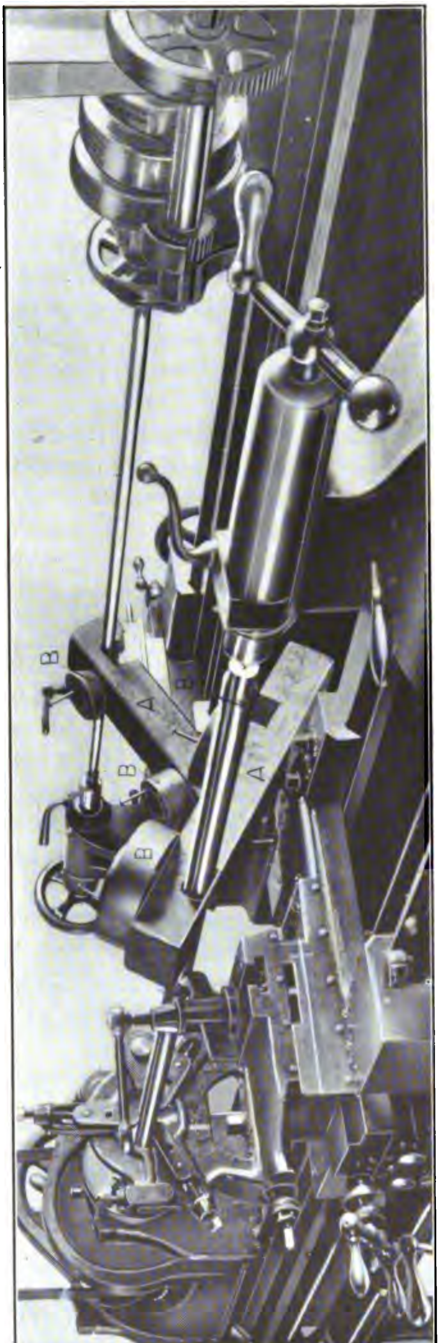


FIG. 174.—Turning slender broaches.

Where broaches are for cylindrical work the teeth are turned in the lathe, making use of the steady-rest to prevent spring. This is a comparatively simple lathe job and needs no explanation.

PLANING BROACH BLANKS

Some broach blanks may be milled by strapping to a milling machine table and using standard cutters. Others are better handled on a planer. Especially is this true of angular, interrupted or formed broaches. For occasional broach planing, special fixtures are desirable although not absolutely necessary, as any good mechanic will find means to machine a broach, if he has to. However, from a commercial manufacturing standpoint, fixtures are certainly needed, and a row of planers used in the J. N. Lapointe shop, is shown in Fig.

175. A number of broaches made in this shop are also shown at the ends of the planing machines. On heavy section broaches, a small table jack is often sufficient to support the work under the cut, but on small, slender work, the type of rests shown on the machine in the fore-ground is desirable. An enlarged view of this last-mentioned machine is shown in Fig. 176. The headstock *A* is provided with a spindle and driver which can be rotated by a worm wheel controlled by the star feed *B* and the trip *C*, if the nature of the work requires it.

Provision is also made for attaching a series of index plates *D* to the live head spindle so that broaches can be machined with any number of divisions. As practically all of the planer work is tapered, the tailstock *E* is provided

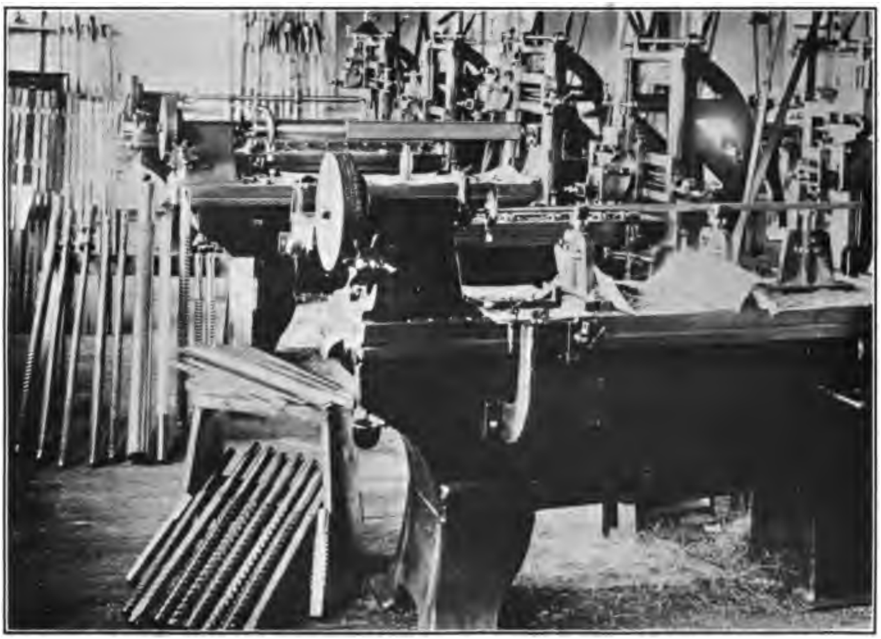


FIG. 175.—A group of planers fitted especially for broach work.

with an elevating device. At *F* is shown a series of planer jacks specially designed for supporting long slender work. The trip *C* for clearness is shown in operating position, although the work *G* is a square broach and, of course, does not require to be turned at each stroke of the planer.

The operation of the trip *C* for such work as requires its use is as follows. As the end of the work passes the tool on the cutting stroke, one arm of the star feed *B* strikes the raised part *H* of the trip *C*. In this position, and with the force applied in this direction, *C* is rigid and the starwheel is rotated. When the planer reverses the starwheel *B* again strikes *H* but the force is applied in the opposite direction and *C* is caused to swing, as the only resistance is that of the coiled spring *I*. As soon as the starwheel has passed

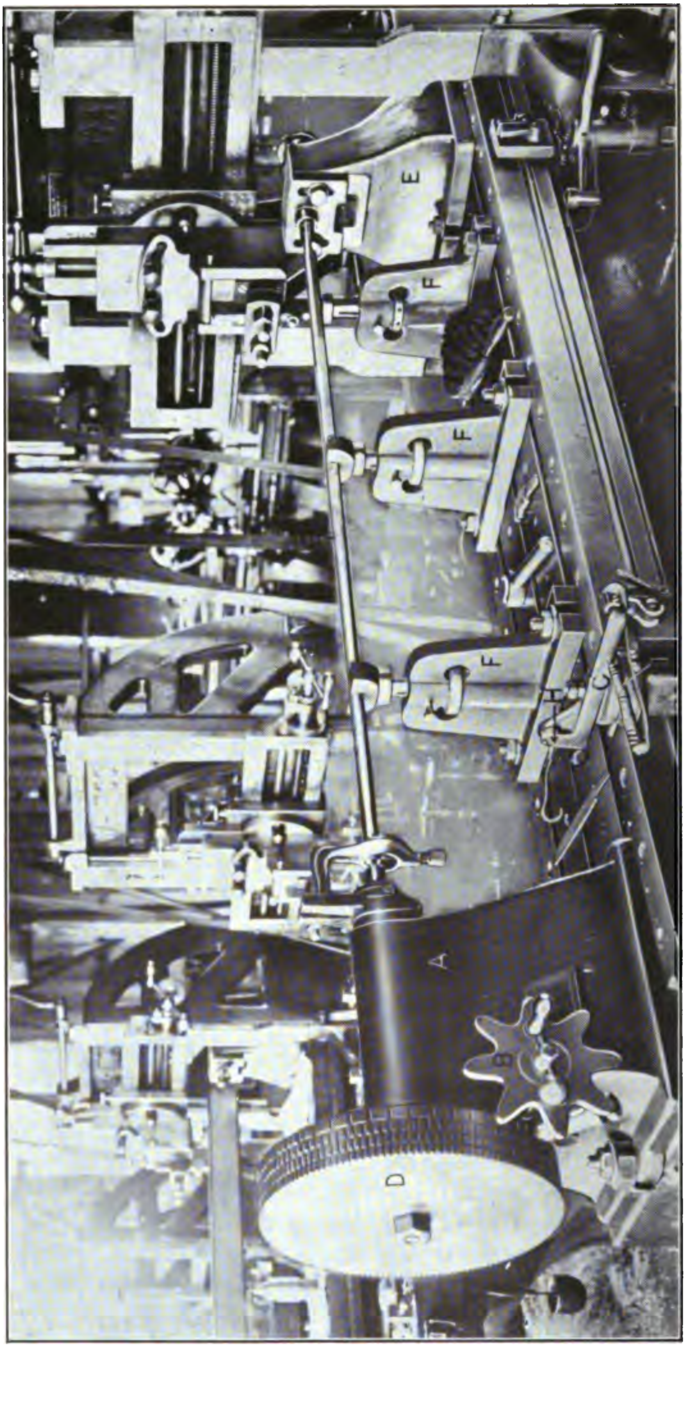


FIG. 176.—Special head and rests for planing broach blanks.

out of engagement with *H*, the spring *I* returns *C* to the position shown. When the planer is operating on work such as shown the trip *C* is swung and clamped so that it does not engage the starwheel.

MILLING THE TEETH

Fig. 177 shows the cutting of the teeth in three keyway broaches at a time on a Whiton rack cutter. The teeth are in this case cut at right angles to the axis of the broach, but another holding fixture permits the cutting of the teeth at an angle. Some care must be exercised when making broaches with the teeth at an angle. There is always a tendency for the broach to crowd over to the side when the teeth are cut on an angle, for that reason the angular direction of the teeth on the opposite sides of a broach should be

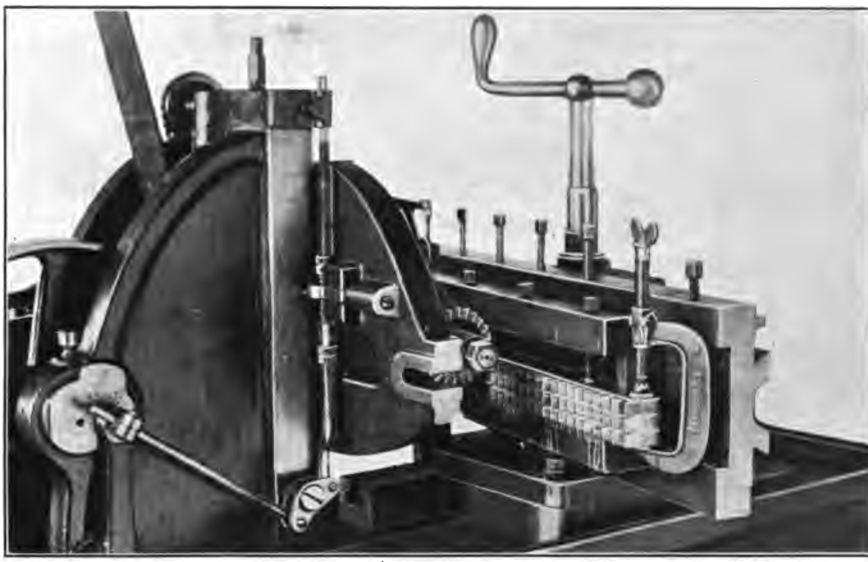


FIG. 177.—Milling broach teeth.

such that the tendency to crowd over in one direction on one side will be counteracted by the direction in which the teeth are sloped on the other side. This point is plainly brought out in the section on the design of diagonal-tooth broaches.

Another tooth milling fixture is shown in Fig. 178. This is used in the shop of the Davis Boring Tool Co., St. Louis, Mo. While this is used in a regular plain milling machine, a special overarm bracket is employed and also a special arbor for the milling cutter. The body of the fixture is mounted on a circular base, on which it may be swung to any desired radial angle. The hinged bracket is so made as to be easily raised or lowered at one end so that the work may be placed at the desired slope. In this hinged bracket is mounted the sliding work holder *A*, into which the broach blank is clamped. These work holders are made in various styles to accommodate the different kinds of broaches made. The work is indexed for the pitch

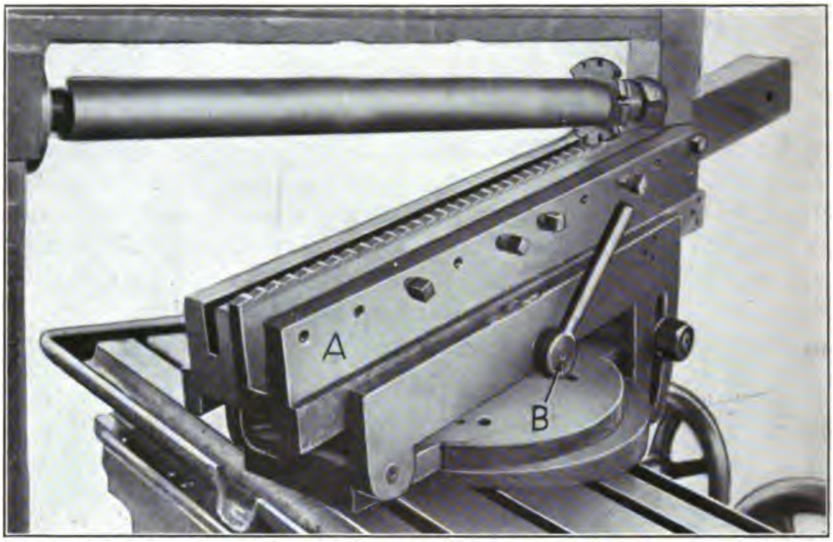


FIG. 178.—Another tooth milling fixture.

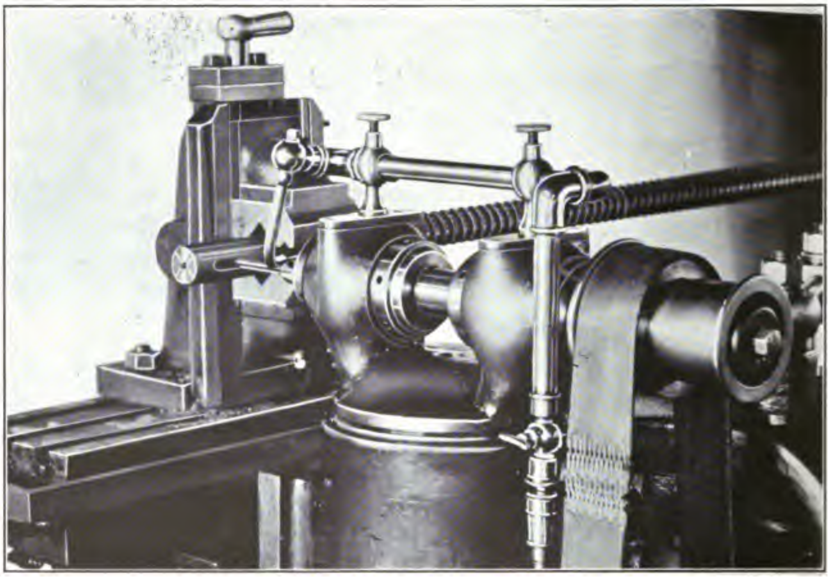


FIG. 179.—Milling out the slot in the shank.

of the teeth by means of a pin in the bracket which fits in properly spaced holes in the work-holder slide. When located, the slide is locked in place for the cut by means of the clamping lever *B*.

MILLING THE SLOT IN THE SHANK

The fixture shown in Fig. 179 is very convenient for holding broaches while milling the slot in the shank. It is also useful for other work of a similar nature. No detailed description is needed, as the engraving plainly shows the construction.

ANGULAR TAPER BROACH MILLING

The following directions for angular taper broach milling were worked out by D. M. Lidell, who writes:

The general procedure in angular taper broach making resolves itself into two operations, turning a frustum of a right circular cone, and then milling it into the frustum of a regular pyramid. It is proposed to give here some simple formulas by which the depth of cut in the milling operation necessary to produce any pyramid from 3 to 15 sides can be readily calculated, provided the diameters of the ends of the frustum of the cone be known.

These calculations are to be made by means of Table XXXI, in which d signifies the diameter of the circular end of the frustum. "Mill off d" signifies the proportion of the total diameter to be taken off in making each face. The table is used as follows: If it is desired to mill a six-sided broach from a frustum of a cone, the end

TABLE XXXI.—CONSTANTS FOR BROACH MILLING

Sides in finished broach	Mill off d	Leave d
3	0.250000	0.750000
4	0.146446	0.853554
5	0.095491	0.904509
6	0.066987	0.933013
7	0.049513	0.950487
8	0.038060	0.961940
9	0.030154	0.969846
10	0.024472	0.975528
11	0.020255	0.979745
12	0.017037	0.982963
13	0.014529	0.985471
14	0.012530	0.987470
15	0.010926	0.989074

diameters of which are 1⅛ in. (1.125 in.) and ⅝ in. (0.625 in.) respectively, the cut at the large end should be 0.066987×1.125 in. = 0.075360 in. deep, and at the small end should be 0.066987×0.625 in. = 0.041867 in. deep. The factor 0.066987 is taken from the table, opposite 6, the number of sides desired, and the second terms are the end diameters d, as left after the cut.

In the particular case under discussion, to make the cut, the tailstock should be elevated by an amount $(1.125 - 0.625)(\frac{1}{2} - 0.066987) = 0.5 \times 0.433013 =$ 0.2165065 in. If, with this elevation, a cut 0.0419 in. deep be taken at the small end, it will be 0.0754 in. deep at the large end. Or, in the general case, if we represent the two diameters by a and b, and the constant taken from the table for any given number of sides as k, the formula for the elevation of the tailstock will be $(a - b)(\frac{1}{2} - k)$.

For instance, if a 15-sided broach were to be cut from a frustum of a cone with diameters $1\frac{3}{16}$ in. and $\frac{7}{16}$ in., elevate the tailstock $(1\frac{3}{16} - \frac{7}{16})(\frac{1}{2} - 0.010926) = (0.75 \times 0.489074) = 0.366805$ in., and then take a cut $\frac{7}{16} \times 0.010926 = 0.004780$ in. deep at the small end; rotate the dividing head 360 deg. $\div$ 15 = 24 deg., and mill again.

It may be noted that while these constants, working on perfect machines, would give perfect results, in practice one must make allowances for the imperfecttions of the dividing head and machine. For instance, it can readily be seen that if a triangular broach is to be milled and the work rotated 120 deg. by the dividing head, and it proves to be only 119 deg., the theoretical cuts will slightly overlap, and the broach will be small. Consequently, after giving the tailstock the theoretical elevation, as nearly as possible, take a cut a little scant (a few ten-thousandths) of the theoretical cut. This will give a small land at the corners, but the radius will be the full theoretical amount.

If anyone is interested in calculating out the above figures, or those of any other number of sides, for himself, the formula is (for a pyramidal frustum of n sides): Mill off $d\left(\frac{1}{2}\left(1 - \cos\frac{360^\circ}{2n}\right)\right)$.

MAKING PUSH BROACHES FOR STEEL WORK

The shop practice of the Spicer Manufacturing Co., Plainfield, N. J., in making push broaches, is the result of several years of experimenting in an effort to find the proper proportions, machining methods, steel and hardening processes for broaches that would give satisfactory results in working out holes of various sizes and lengths in tough, 40-point steel forgings from which its universal joints are made.

Besides having the teeth of proper size and pitch, with plenty of chip clearance, ease of machining should be considered in designing a broach, especially if many of them are used. If the machining is difficult, the cost of keeping a large number of sets to size soon becomes burdensome to the most prosperous shop.

The objection frequently heard regarding push broaches is that they have a tendency to twist or creep in the work, but if properly made this trouble will not be encountered, and no subpress or other guides will be necessary.

Machining Broaches

In machining broaches like those shown in Fig. 180, which are for a square hole with round corners, according to the standard of the Society of Automotive Engineers, the practice at the Spicer shop is to center and turn the blank according to the dimensions given in the specification for a certain size hole. Specifications of the kind referred to were given in a previous article for a large range of push broaches.

After the blank has been turned, the teeth are cut the proper pitch and diameter. It will be seen that this is an ordinary lathe job, the blanks for

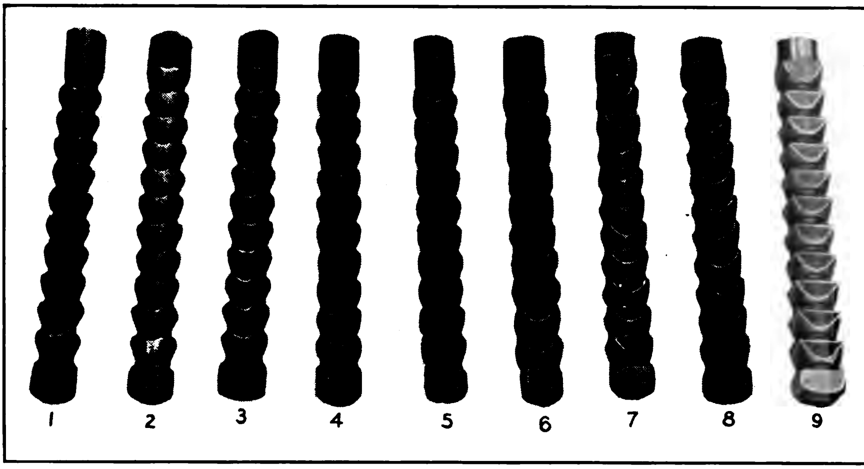


FIG. 180.—A set of broaches for a round-cornered square hole.

all common sizes being short enough and stiff enough, the length ranging from 5 to 12 in., according to diameter, to be turned to the given dimensions without trouble of any kind.

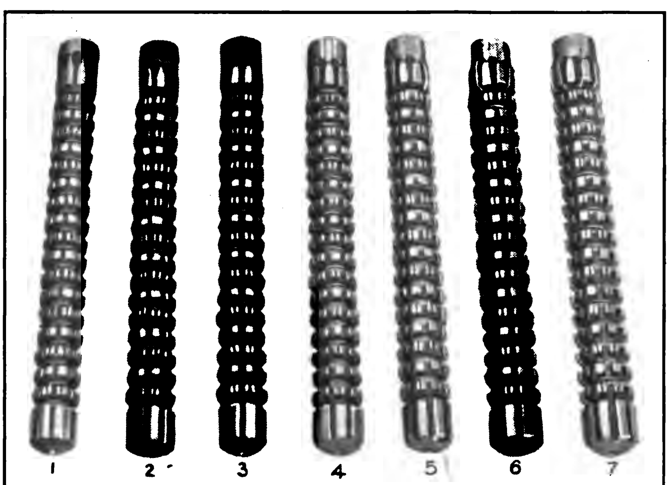


FIG. 181.—A set of broaches for a ten-spline hole.

The next step is to place the blanks between the centers of a miller, using a dividing head for indexing purposes. The flats of each broach are milled *parallel with the center line* and *all the same distance from this line.* This differs from the more common practice, in milling square broach teeth, which is to step up each one separately. The advantage and saving of time by the former method is obvious.

From this it will be seen that the matter of tooth increase sizes for this class of broaches is entirely one of circular turning or grinding, an operation easily gaged by micrometers. This is not the case where the flats are stepped up, as often the blank must be indexed several times to get the desired distance between parallel flats.

The round or pilot ends of a set of broaches of the type shown are all made the same diameter, and the first "teeth" do not cut but merely act as guides in the grooves cut by the preceding broach. The large end is turned cone-shaped, to fit the push pin used in the press ram to force the broach down through the hole. This automatically centers the broach, and the pilot and pilot teeth effectually guide it.

These, together with the accurate method of grinding the cutting teeth, prevent all tendency to twist or creep in the work. Of course, the work is accurately centered under the broach by means of a locating ring or bushing. It is also the practice to accurately size the hole to be broached, by means of a sizing or "leader" broach, so that the pilots will fit, and not bind or wobble.

Multiple-spline Broaches

The multiple-spline broaches are turned in practically the same way as the square ones, but the milling is, of course, different. The bottom of the flutes of each broach are milled parallel with the center line all the way, and, in order to break up the chips, every other tooth of a line is grooved, as shown in the ten-spline set in Fig. 181. This takes less power and produces a smoother cut, there being less tendency to tear the metal.

The pilot teeth in these broaches are beveled on each side of the entering end, to facilitate insertion, and guide the broach without a tendency to "scrape a twist" one way or the other. An enlarged view of some of the cutting teeth of ten-spline broaches is given in Fig. 182.

Samples of the holes cut by the square and six-spline broaches are shown in the parts of the universal joints, Fig. 183. Very accurate work is done on these parts and in some cases as high as 23 push broaches are used in a set.

Great care is taken in grinding the teeth, after hardening, to produce just the right amount of undercut and radius at the base of the teeth to produce a nice curling chip. The chips shown in Fig. 184 are evidence of the success of this work.

HARDENING BROACHES

Since the hardening of as important a tool as a broach is usually done by a skilled hardener who knows his steel and how to handle it, detailed

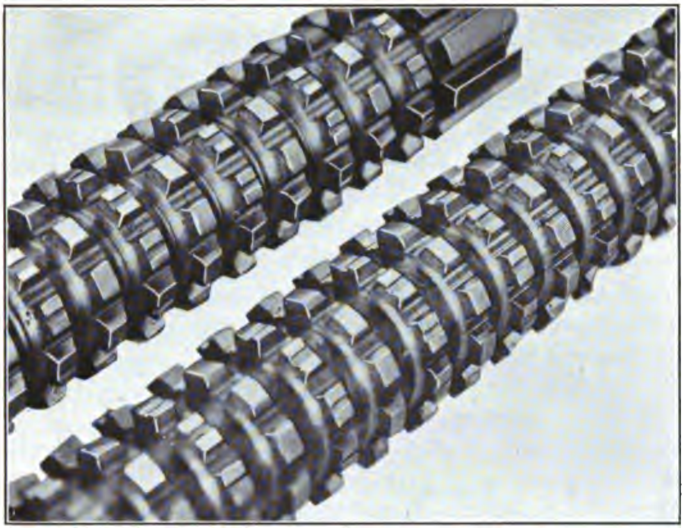


FIG. 182.—Details of the teeth of multiple-spline broach.

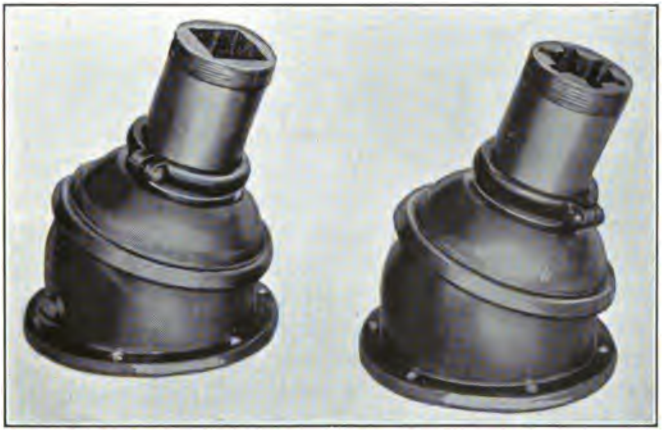


FIG. 183.—Parts of universal joints.

FIG. 184.—Chips, showing curl given by properly shaped tooth.

directions are superfluous, but it will not be amiss to outline in a general way how some firms handle their work. As previously stated, broaches are made of four kinds of steel: Mild steel, case-hardened, carbon steel, alloy steel and high-speed steel, the last named being of the tungsten class. Of the alloy steels, carbon-vanadium seems to give very good satisfaction for broaches. This steel is simply a high-grade carbon steel containing vanadium, but no tungsten or chromium. The addition of vanadium gives the steel a greater heating range without coarsening the grain. This steel is recommended to be hardened at from 1350° to 1425°F. The temperature is then usually drawn to about 460°F. Where carbon steel is used for broaches the carbon content should range around 1.0 to 1.10 points. To prevent excessive warping, it is a good plan to rough out a broach and then anneal it before proceeding farther. Open-hearth steel of about 0.25 points carbon content makes a very good grade where case-hardening is resorted to. The general procedure is to pack these broaches in a tube or box with ground bone, and heat to about 1700°F. The box is then allowed to cool slowly without disturbing the contents. It is then again reheated to about 1475° and quenched. The temper is then drawn to about 370° or 380°F., or in some cases 15° or 20° less than this.

When a broach has become warped in the hardening process, it may be straightened between wooden blocks with a mandrel press, or other similar means. Better results are usually obtained if the straightening is done at the time the temper is drawn. The warped place may be heated with a gas torch or any other means that can be easily controlled, care being taken not to heat the spot hot enough to draw the temper, which is sure to happen if the drawing temperature is exceeded. In handling any unfamiliar steel, it is the better plan to closely follow the maker's directions as to the temperatures allowable, as they can generally be relied upon to give the user the benefit of their much wider experience.

The method of hardening used in the Alco shop is as follows:

The steel used in making the Alco broaches is known as Styrian Blue Label, and the broaches are packed in large tubes with a screw cap on each end. The packing material consists of charcoal 2 parts and leather 1 part, and there should be at least 1½ in. of the mixture on each side.

The tubes are put into a Brown & Sharpe coal furnace at about 1000°F. and heated to 1500°, the time depending on the size of broach being heated. For a 1-in. broach the time taken to heat properly and allow the carbon to "soak in" is 2 hr. For a 1¼-in. broach, 2½ hr., and a 1½-in. broach, 3 hr., or an average of an additional half hour for every quarter-inch increase in size.

When properly heated, the broaches are quenched in a large deep tank filled with thin linseed oil, being held by the shank and plunged vertically. This leaves the teeth extremely hard and tough and the inside comparatively soft. The broaches are next drawn in oil to a light straw color, or to a temperature of between 400° and 450°F. Any necessary straightening is now done in a straightening press, careful heating being done with a torch, but this is seldom needed with this steel and method of hardening.

Two or 3 years ago, I wrote regarding push-broach practice that the selection of the proper steel and the method of hardening have been the ruin of many a would-be broach maker. Many have tried the most expensive steels obtainable, only to find, after carefully machining the difficult stuff, that it was wholly unsuited for the purpose.

After running the entire gamut of the steel scale, the Spicer Manufacturing Co. has settled on an open-hearth steel of from 20- to 25-point carbon content. Broaches made from this steel are easily machined, give no trouble in hardening or tempering, and have a life of from 2000 to 10,000 pieces each, before reaching the scrapping limit of 0.002-in. undersize.

The hardening process is the ordinary one of case-hardening, the broaches being packed in tubes, with slightly charred ground bone, and heated to about 1700°F. for from 4 to 8 hr., depending on the size of the tools being hardened.

The quenching is first done in water, the broaches being plunged straight down into the tank, and held under until the teeth turn black, then finish cooled in oil. The drawing, or tempering, is done in an oil bath heated to 350°F., which, it will be noted, is considerably less than for tool-steel tempering.

GRINDING BROACHES

The grinding methods for all sorts of shapes are now so familiar to every shop man that it is useless to go into details here. With the outlines given in the chapter on design, any ordinary grinder should be able to finish a broach on his grinding machine without much instruction. Round broaches are of course the easiest to grind, then next is the common keyway broach of the sliding-blade type. Following this is the square broach and thence on to the more difficult forms.

A simple method of grinding keyway cutter bars is shown in Fig. 185. The grinder is fitted with a magnetic chuck and the cutters are ground all over. The bars may be removed at any time for measuring and instantly replaced without any trouble whatever. By tilting the chuck the back of the broach may be ground to any taper desired.

We have a great many keyway broaches to sharpen, says M. V. D. in the *American Machinist*, and so we have made the grinding fixture shown in Fig. 186.

The cutters are about 18 in. long and have been found by trial to work best when given a taper of about 1/32 in. in that distance. The fixture consists of a flat piece of cast iron, planed all over and bolted on the table of the cutter grinder so that it is flush with the edge of the table nearest the wheel. This piece is shown at *A*. The table is swiveled to get the angle *X*, which is the clearance desired on the teeth. Bolted to *A* is a bracket *B*, which carries the lever *E*, and also acts as a cap or guide for a small angle-shaped gage *C*, which freely slides in and under it.

FIG. 185.—Sizing keyway broaches after hardening.

One end of *E* is made eccentric, so that when thrown back it locks the gage piece *C* against *D*; the other end carries a gage *F*, which engages with the teeth of the cutter to be ground. *D* is a taper piece slightly longer than the cutter, with one end bent so that the end of the cutter carries it along when moved to grind the next tooth. This end of *D* is 1/32 in. thinner than the other, or just the clearance desired on the cutter.

To operate, place the pin *G* in the hole, as shown, bring the front of the tooth *I* against the gage *F*, which also places cutting edge in line with the point of the gage *C*, against which it must be drawn; next slide *D* along until the end touches the cutter, then pull the lever *E* back, thereby locking *C* and *D* against *A*.

We now have three solid points, *G*, *C* and *D*, to locate the cutter. The tooth *I* is fed past the face of the cup wheel by moving the table of the grinder. To grind, the next tooth *E* is again swung forward, releasing *D*, and the cutter is moved to bring the next tooth against *F*; it carries *D* along with it where it is locked, and the tooth is ground in a similar manner to that previously described.

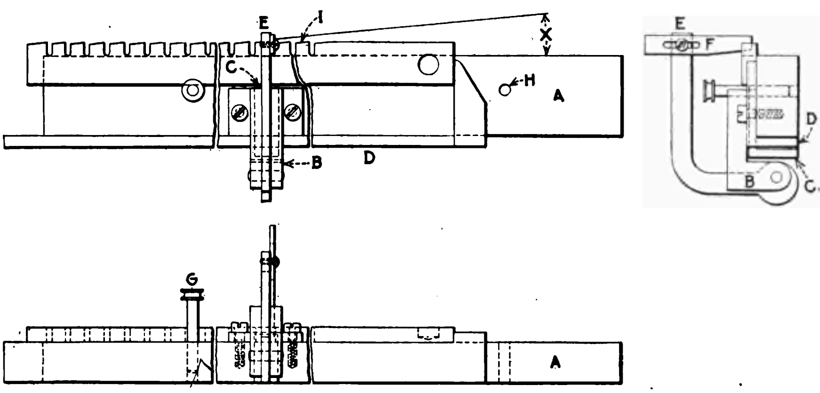


FIG. 186.—Fixture for grinding keyway cutters.

As the taper piece *D* is fed along, it gradually gets thicker, thereby causing the gage *C* to be slightly receded for each succeeding tooth. When the cutter has been about half ground, pin *G* is taken out and put in the hole *H*, which is placed about 1/64 in. back of the line of the other hole and the gage piece *C*; this is to allow for the taper, but does not need to be accurate, as the grinding is done directly in front of the gage *C*, and any variation in the location of *H* would only mean a difference in clearance and not in taper.

A method of grinding relief on broach teeth, used in the J. N. Lapointe shop, is shown in Fig. 187. The work *A* is a finishing broach ground to size in a previous operation. Indexing is accomplished by means of the finger *B* and the work is fed past the wheel.

In speaking of work done on square and spline broaches, a writer in the *American Machinist* says:

The grinding is done between index centers on a regular grinder, using a free cutting wheel. The six-spline broaches are ground by using a thin wheel, set over the center line and grinding lengthwise of the flutes, rotating

FIG. 187.—Relieving the teeth.

the broach the necessary amount to grind the radial bottom and sides of the flute.

The lands of the teeth are ground perfectly parallel with the center line of the broach, and in case any relief seems needed in practice, it is given by hand by means of a small, hard oilstone. Just back of the land, which is usually 1/32 in., there is a relief of about 2½ deg. given.

TESTING DEPTH OF CUT PER TOOTH

After a broach has been ground, it is a good plan to try it out to see that none of the teeth have a tendency to "hog in" or cut more than their due share, for if they do it is liable to result in clogging with chips, springing or even breaking of the broach, to say nothing of ruining the work. Several things may be the cause of unevenly cutting teeth, either warping from the hardening process, which has not been eliminated or else from the release of unexpected strains during the grinding, or secondly, from uneven grinding of the teeth, which may be the operator's fault or possibly a result of the warping mentioned. In any case the broach should be tested out before being put into actual service on any valuable work. To do this testing, first use a piece with the required size and shape of hole in it, but not longer than twice the pitch of the teeth. The broach should be run slowly through this and the amount of chips made by each tooth carefully noted. The high teeth can then be stoned down, and the broach again run through a slightly longer piece, finally running it through the full length of hole it is to broach in actual use. In this test, not only should the amount of chips be noted, but also whether they have the proper curl for the material on which they are working. If any radical faults are seen, they should be corrected and note made of them to be avoided in future broach making.

APPENDIX

Recommended S.A.E. practice for the dimensions of square broached fittings, 6-spline fittings, 10-spline fittings, 4-spline fittings and taper fittings with castle nuts.

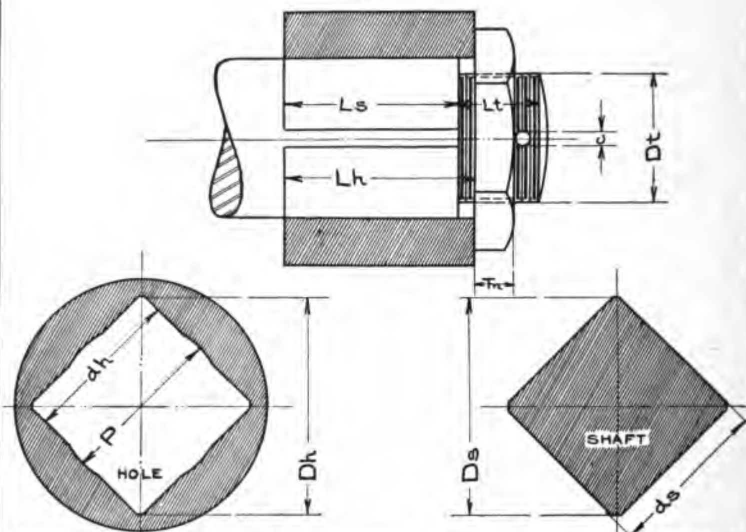
TABLE XXXII

SQUARE FITTINGS

RECOMMENDED

S.A.E. PRACTICE

1912

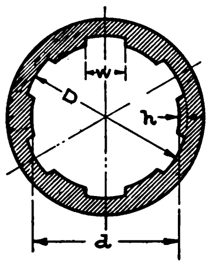
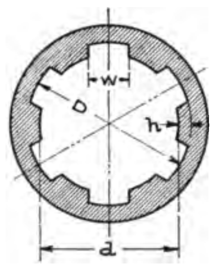
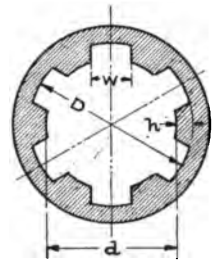


Nominal Dia.	Permanent Fit $\frac{ds}{Ds}=.80$														Slip Fit $\frac{ds}{Ds}=.73$					
	P	ds	dh	Ds	Dh	Ls	Lh	Lt	Dt	*N	Tn	*H	c	*Cp	P	ds	dh	Ds	Dh	*Cs
1/4	.193	.1895 .1885	.1875 .1865	.250 .245	.260 .252	5/16	3/8	5/16	3/16	32	5/32	9/32	1/16		.257	.248 .247	.250 .249	.3437 .3387	.3537 .3457	2.6
3/8	.290	.2832 .2822	.2812 .2802	.375 .370	.385 .377	7/16	1/2	7/16	1/4	28	7/32	3/8	5/64		.386	.373 .372	.375 .374	.5156 .5106	.5256 .5176	5.9
1/2	.386	.3770 .3760	.3750 .3740	.500 .495	.510 .502	11/16	3/4	7/16	5/16	24	15/64	1/2	5/64	49	33/64	.498 .497	.500 .499	.6875 .6825	.6975 .6895	10.
5/8	33/64	.5020 .5010	.5000 .4990	.625 .620	.635 .627	11/16	3/4	1/2	1/2	20	1/4	3/4	3/32	67	41/64	.623 .622	.625 .624	.8437 .8387	.8537 .8457	16.
3/4	37/64	.5645 .5635	.5625 .5615	.750 .745	.760 .752	15/16	1	1/2	1/2	20	1/4	3/4	3/32	105	49/64	.748 .747	.750 .749	1.031 1.026	1.051 1.036	23.
7/8	45/64	.6895 .6885	.6875 .6865	.875 .870	.885 .877	1 1/8	1 1/4	5/8	5/8	20	5/16	1	1/8	130	29/32	.873 .872	.875 .874	1.187 1.182	1.207 1.192	32.
1	27/32	.8155 .8145	.8125 .8115	1.000 .995	1.020 1.005	1 3/8	1 1/2	5/8	3/4	20	5/16	1	1/8	175	1 1/32	.998 .997	1.000 .999	1.375 1.370	1.395 1.380	42.
1 1/8	29/32	.8780 .8770	.8750 .8740	1.125 1.120	1.145 1.130	1 3/8	1 1/2	5/8	3/4	20	5/16	1	1/8	250	1 5/32	1.123 1.122	1.125 1.124	1.562 1.557	1.582 1.567	53.
1 1/4	1 1/32	1.003 1.002	1.000 .999	1.250 1.245	1.270 1.255	1 3/8	1 1/2	5/8	1	20	5/16	1 1/2	1/8	260	1 9/32	1.248 1.247	1.250 1.249	1.687 1.682	1.707 1.692	66.
1 3/8	1 5/32	1.128 1.127	1.125 1.124	1.375 1.370	1.395 1.380	1 7/8	2	5/8	1	20	5/16	1 1/2	1/8	300	1 27/64	1.373 1.372	1.375 1.374	1.875 1.870	1.895 1.880	79.
1 1/2	1 5/32	1.128 1.127	1.125 1.124	1.500 1.495	1.520 1.505	1 7/8	2	5/8	1	20	5/16	1 1/2	1/8	450	1 35/64	1.498 1.497	1.500 1.499	2.062 2.057	2.082 2.067	94.
1 3/4	1 27/64	1.378 1.377	1.375 1.374	1.750 1.745	1.770 1.755	2 1/8	2 1/4	3/4	1 1/4	18	7/16	2 1/8	1/8	540	1 13/16	1.748 1.747	1.750 1.749	2.375 2.370	2.395 2.380	128.
2	1 35/64	1.504 1.503	1.5000 1.4985	2.000 1.995	2.020 2.005	2 7/8	3	3/4	1 1/4	18	7/16	2 1/8	1/8	800	2 1/16	1.9975 1.9965	2.0000 1.9985	2.750 2.745	2.770 2.755	168.
2 1/4	1 13/16	1.754 1.753	1.7500 1.7485	2.250 2.245	2.270 2.255	2 7/8	3	3/4	1 1/4	18	7/16	2 1/8	1/8	940	2 5/16	2.2475 2.2465	2.2500 2.2485	3.062 3.057	3.082 3.067	210.
2 1/2	2 1/16	2.004 2.003	2.0000 1.9985	2.500 2.495	2.520 2.505	3 3/8	3 1/2	1 1/8	2	16	5/8	3 1/8	3/16	1050	2 37/64	2.4975 2.4965	2.5000 2.4985	3.437 3.432	3.457 3.442	263.
2 3/4	2 5/16	2.254 2.253	2.2500 2.2485	2.750 2.745	2.770 2.755	3 3/8	3 1/2	1 1/8	2	16	5/8	3 1/8	3/16	1250	2 55/64	2.7475 2.7465	2.7500 2.7485	3.750 3.745	3.770 3.755	315.
3	2 37/64	2.504 2.503	2.500 2.498	3.000 2.995	3.020 3.005	3 7/8	4	1 1/8	2	16	5/8	3 1/8	3/16	1300	3 3/32	2.997 2.996	3.000 2.998	4.125 4.120	4.145 4.130	379.
3 1/2	2 56/64	2.754 2.753	2.750 2.748	3.500 3.495	3.520 3.505	4 3/8	4 1/2	1 1/4	2 1/2	14	3/4	3 7/8	1/4	2200	3 39/64	3.497 3.496	3.500 3.498	4.750 4.745	4.770 4.755	514.
4	3 23/64	3.254 3.253	3.250 3.248	4.000 3.995	4.020 4.005	5 3/8	5 1/2	1 1/4	2 1/2	14	3/4	3 7/8	1/4	2800	4 1/8	3.997 3.996	4.000 3.998	5.500 5.495	5.520 5.505	672.

* N - THOS. PER INCH. H - SHORT DIA. OF NUT. Cp - CAPACITY IN FT. LBS. PER 1" LENGTH AT 10000 LBS. PRESS. PER SQ. IN. Cs - CAPACITY IN FT. LBS. PER 1" LENGTH AT 1000 LBS. PRESS. PER SQ. IN.

TABLE XXXIII

6 SPLINE FITTINGS

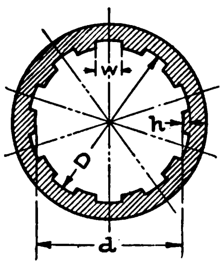
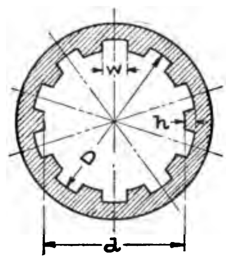
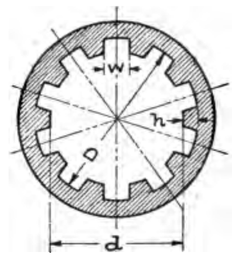
PERMANENT FIT	TO SLIDE WHEN NOT UNDER LOAD	TO SLIDE WHEN UNDER LOAD
		
6-A	6-B	6-C
w = .25 D h = .05 D d = .90 D	w = .25 D h = .075 D d = .85 D	w = .25 D h = .10 D d = .80 D

NOMINAL DIA.	D	d	w	T		D	d	w	T		D	d	w	T	
3/4	.750 / .749	.675 / .674	.188 / .187	80		.750 / .749	.638 / .637	.188 / .187	117		.750 / .749	.600 / .599	.188 / .187	152	
7/8	.875 / .874	.788 / .787	.219 / .218	109		.875 / .874	.744 / .743	.219 / .218	159		.875 / .874	.700 / .699	.219 / .218	207	
1	1.000 / .999	.900 / .899	.250 / .249	143		1.000 / .999	.850 / .849	.250 / .249	208		1.000 / .999	.800 / .799	.250 / .249	270	
1 1/8	1.125 / 1.124	1.013 / 1.012	.281 / .280	180		1.125 / 1.124	.956 / .955	.281 / .280	263		1.125 / 1.124	.900 / .899	.281 / .280	342	
1 1/4	1.250 / 1.249	1.125 / 1.124	.313 / .312	223		1.250 / 1.249	1.063 / 1.062	.313 / .312	325		1.250 / 1.249	1.000 / .999	.313 / .312	421	
1 3/8	1.375 / 1.374	1.238 / 1.237	.344 / .343	269		1.375 / 1.374	1.169 / 1.168	.344 / .343	393		1.375 / 1.374	1.100 / 1.099	.344 / .343	510	
1 1/2	1.500 / 1.499	1.350 / 1.349	.375 / .374	321		1.500 / 1.499	1.275 / 1.274	.375 / .374	468		1.500 / 1.499	1.200 / 1.199	.375 / .374	608	
1 5/8	1.625 / 1.624	1.463 / 1.462	.406 / .405	376		1.625 / 1.624	1.381 / 1.380	.406 / .405	550		1.625 / 1.624	1.300 / 1.299	.406 / .405	713	
1 3/4	1.750 / 1.749	1.575 / 1.574	.438 / .437	436		1.750 / 1.749	1.488 / 1.487	.438 / .437	637		1.750 / 1.749	1.400 / 1.399	.438 / .437	827	
2	2.000 / 1.998	1.800 / 1.798	.500 / .498	570		2.000 / 1.998	1.700 / 1.698	.500 / .498	833		2.000 / 1.998	1.600 / 1.598	.500 / .498	1080	
2 1/4	2.250 / 2.248	2.025 / 2.023	.563 / .561	721		2.250 / 2.248	1.913 / 1.912	.563 / .561	1052		2.250 / 2.248	1.800 / 1.798	.563 / .561	1367	
2 1/2	2.500 / 2.498	2.250 / 2.248	.625 / .623	891		2.500 / 2.498	2.125 / 2.123	.625 / .623	1300		2.500 / 2.498	2.000 / 1.998	.625 / .623	1688	
3	3.000 / 2.998	2.700 / 2.698	.750 / .748	1283		3.000 / 2.998	2.550 / 2.548	.750 / .748	1873		3.000 / 2.998	2.400 / 2.398	.750 / .748	2430	

T = 1000 X 6 X MEAN R X h · X 1 = INCH-POUNDS TORQUE CAPACITY PER INCH BEARING LENGTH AT 1000 LBS. PRESSURE PER SQUARE INCH ON SIDES OF SPLINES. NO ALLOWANCE IS MADE FOR RADII ON CORNERS NOR FOR CLEARANCES.

TABLE XXXIV.

10 SPLINE FITTINGS

PERMANENT FIT	TO SLIDE WHEN NOT UNDER LOAD	TO SLIDE WHEN UNDER LOAD
		
10-A	10-B	10-C
w = .156 D h = .045 D d = .91 D	w = .156 D h = .07 D d = .86 D	w = .156 D h = .095 D d = .81 D

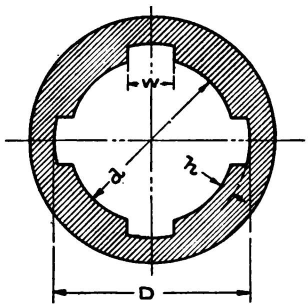
NOMINAL DIA.	D	d	w	T	D	d	w	T	D	d	w	T
3/4	.750/.749	.683/.682	.117/.116	120	.750/.749	.645/.644	.117/.116	183	.750/.749	.608/.607	.117/.116	241
7/8	.875/.874	.796/.795	.137/.136	165	.875/.874	.753/.752	.137/.136	248	.875/.874	.709/.708	.137/.136	329
1	1.000/.999	.910/.909	.156/.155	215	1.000/.999	.860/.859	.156/.155	326	1.000/.999	.810/.809	.156/.155	430
1 1/8	1.125/1.124	1.024/1.023	.176/.175	271	1.125/1.124	.968/.967	.176/.175	412	1.125/1.124	.911/.910	.176/.175	545
1 1/4	1.250/1.249	1.138/1.137	.195/.194	336	1.250/1.249	1.075/1.074	.195/.194	508	1.250/1.249	1.013/1.012	.195/.194	672
1 3/8	1.375/1.374	1.251/1.250	.215/.214	406	1.375/1.374	1.183/1.182	.215/.214	614	1.375/1.374	1.114/1.113	.215/.214	813
1 1/2	1.500/1.499	1.365/1.364	.234/.233	483	1.500/1.499	1.290/1.289	.234/.233	732	1.500/1.499	1.215/1.214	.234/.233	967
1 5/8	1.625/1.624	1.479/1.478	.254/.253	566	1.625/1.624	1.398/1.397	.254/.253	860	1.625/1.624	1.316/1.315	.254/.253	1135
1 3/4	1.750/1.749	1.593/1.592	.273/.272	658	1.750/1.749	1.505/1.504	.279/.272	997	1.750/1.749	1.418/1.417	.273/.272	1316
2	2.000/1.998	1.820/1.818	.312/.310	860	2.000/1.998	1.720/1.718	.312/.310	1302	2.000/1.998	1.620/1.618	.312/.310	1720
2 1/4	2.250/2.248	2.048/2.046	.351/.349	1088	2.250/2.248	1.935/1.933	.351/.349	1647	2.250/2.248	1.823/1.821	.351/.349	2176
2 1/2	2.500/2.498	2.275/2.273	.390/.388	1343	2.500/2.498	2.150/2.148	.390/.388	2034	2.500/2.498	2.025/2.023	.390/.388	2688
3	3.000/2.998	2.730/2.728	.468/.466	1934	3.000/2.998	2.580/2.578	.468/.466	2929	3.000/2.998	2.430/2.428	.468/.466	3869

T = 1000 X 10 X MEAN R X h X 1 = INCH-POUNDS TORQUE CAPACITY PER INCH BEARING LENGTH AT 1000 LBS. PRESSURE PER SQUARE INCH ON SIDES OF SPLINES. NO ALLOWANCE IS MADE FOR RADII ON CORNERS NOR FOR CLEARANCES.

TABLE XXXV

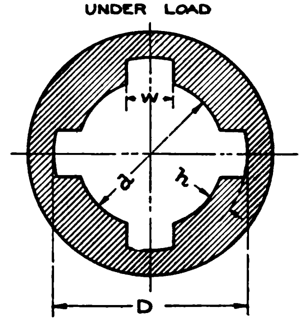
4 SPLINE FITTINGS

PERMANENT FIT	TO SLIDE WHEN NOT UNDER LOAD



4-A

w = .241 D
h = .075 D
d = .850 D



4-B

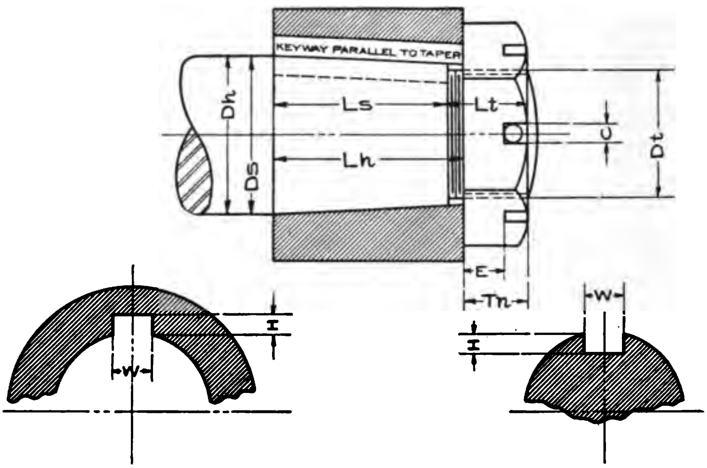
w = .241 D
h = .125 D
d = .750 D

NOMINAL DIA.	D (4-A)	d (4-A)	w (4-A)	h (4-A)	T (4-A)		D (4-B)	d (4-B)	w (4-B)	h (4-B)	T (4-B)	
3/4	.750 / .749	.637 / .636	.181 / .180	.056 / .055	78		.750 / .749	.562 / .561	.181 / .180	.094 / .093	123	
7/8	.875 / .874	.744 / .743	.211 / .210	.066 / .065	107		.875 / .874	.656 / .655	.211 / .210	.109 / .108	167	
1	1.000 / .999	.850 / .849	.241 / .240	.075 / .074	139		1.000 / .999	.750 / .749	.241 / .240	.125 / .124	219	
1 1/8	1.125 / 1.124	.956 / .955	.271 / .270	.084 / .083	175		1.125 / 1.124	.844 / .843	.271 / .270	.141 / .140	277	
1 1/4	1.250 / 1.249	1.062 / 1.061	.301 / .300	.094 / .093	217		1.250 / 1.249	.937 / .936	.301 / .300	.156 / .155	341	
1 3/8	1.375 / 1.374	1.169 / 1.168	.331 / .330	.103 / .102	262		1.375 / 1.374	1.031 / 1.030	.331 / .330	.172 / .171	414	
1 1/2	1.500 / 1.499	1.275 / 1.274	.361 / .360	.112 / .111	311		1.500 / 1.499	1.125 / 1.124	.361 / .360	.187 / .186	491	
1 5/8	1.625 / 1.624	1.381 / 1.380	.391 / .390	.122 / .121	367		1.625 / 1.624	1.219 / 1.218	.391 / .390	.203 / .202	577	
1 3/4	1.750 / 1.749	1.487 / 1.486	.422 / .421	.131 / .130	424		1.750 / 1.749	1.312 / 1.311	.422 / .421	.219 / .218	670	
2	2.000 / 1.998	1.700 / 1.698	.482 / .480	.150 / .148	555		2.000 / 1.998	1.500 / 1.498	.482 / .480	.250 / .248	875	
2 1/4	2.250 / 2.248	1.912 / 1.910	.542 / .540	.169 / .167	703		2.250 / 2.248	1.687 / 1.685	.542 / .540	.281 / .279	1106	
2 1/2	2.500 / 2.498	2.125 / 2.123	.602 / .600	.187 / .185	865		2.500 / 2.498	1.875 / 1.873	.602 / .600	.312 / .310	1365	
3	3.000 / 2.998	2.550 / 2.548	.723 / .721	.225 / .223	1249		3.000 / 2.998	2.250 / 2.248	.723 / .721	.375 / .373	1969	

T = 1000 X 4 X MEAN R X h X 1 = INCH-POUNDS TORQUE CAPACITY PER INCH BEARING LENGTH AT 1000 LBS. PRESSURE PER SQUARE INCH ON SIDES OF SPLINES. NO ALLOWANCE IS MADE FOR RADII ON CORNERS NOR FOR CLEARANCES.

TABLE XXXVI

TAPER FITTINGS



Nominal Dia.	TAPER 1 1/2 IN 12													
	Ds Shaft	Dh Hole	Ls	Lh	Lt	Dt	Thds per inch	E	Tn	Short dia of nut	W	H	Square Key	C
1/4	.250 / .249	.248 / .247	5/16	3/8	5/16	3/16	32	5/32	1/4	9/32	.0625 / .0620	.0337 / .0327	.0635 / .0630	3/32
3/8	.375 / .374	.373 / .372	7/16	1/2	7/16	5/16	24	15/64	3/8	1/2	.0937 / .0932	.0494 / .0484	.0947 / .0942	7/641
1/2	.500 / .499	.498 / .497	11/16	3/4	7/16	5/16	24	15/64	3/8	1/2	.1250 / .1245	.0650 / .0640	.1260 / .1255	7/64
5/8	.625 / .624	.623 / .622	11/16	3/4	1/2	1/2	20	1/4	7/16	3/4	.1562 / .1557	.0806 / .0796	.1572 / .1567	1/8
3/4	.750 / .749	.748 / .747	15/16	1	1/2	1/2	20	1/4	7/16	3/4	.1875 / .1870	.0963 / .0953	.1885 / .1880	1/8
7/8	.875 / .874	.873 / .872	1 1/8	1 1/4	5/8	5/8	20	5/16	1/2	1	.2500 / .2490	.1275 / .1265	.2510 / .2505	5/32
1	1.001 / .999	.997 / .995	1 3/8	1 1/2	5/8	3/4	20	5/16	1/2	1	.2500 / .2490	.1275 / .1265	.2510 / .2505	5/32
1 1/8	1.126 / 1.124	1.122 / 1.120	1 3/8	1 1/2	5/8	3/4	20	5/16	1/2	1	.3125 / .3115	.1610 / .1590	.3140 / .3130	5/32
1 1/4	1.251 / 1.249	1.247 / 1.245	1 3/8	1 1/2	5/8	1	20	5/16	1/2	1 1/2	.3125 / .3115	.1610 / .1590	.3140 / .3130	5/32
1 3/8	1.376 / 1.374	1.372 / 1.370	1 7/8	2	5/8	1	20	5/16	1/2	1 1/2	.3750 / .3740	.1925 / .1905	.3765 / .3755	5/32
1 1/2	1.501 / 1.499	1.497 / 1.495	1 7/8	2	5/8	1	20	5/16	1/2	1 1/2	.3750 / .3740	.1925 / .1905	.3765 / .3755	5/32
1 3/4	1.751 / 1.749	1.747 / 1.745	2 1/8	2 1/4	3/4	1 1/4	18	7/16	5/8	2 1/8	.4375 / .4365	.2237 / .2217	.4390 / .4380	5/32
2	2.001 / 1.999	1.997 / 1.995	2 7/8	3	3/4	1 1/4	18	7/16	5/8	2 1/8	.5000 / .4990	.2550 / .2530	.5015 / .5005	5/32
2 1/4	2.252 / 2.248	2.245 / 2.242	2 7/8	3	3/4	1 1/4	18	7/16	5/8	2 1/8	.5625 / .5610	.2962 / .2912	.5645 / .5630	5/32
2 1/2	2.502 / 2.498	2.495 / 2.492	3 3/8	3 1/2	1 1/8	2	16	5/8	1	3 1/8	.6250 / .6235	.3275 / .3225	.6270 / .6255	7/32
2 3/4	2.752 / 2.748	2.745 / 2.742	3 3/8	3 1/2	1 1/8	2	16	5/8	1	3 1/8	.6875 / .6860	.3587 / .3537	.6895 / .6880	7/32
3	3.002 / 2.998	2.995 / 2.992	3 7/8	4	1 1/8	2	16	5/8	1	3 1/8	.7500 / .7485	.3900 / .3850	.7520 / .7505	7/32
3 1/2	3.502 / 3.498	3.495 / 3.492	4 3/8	4 1/2	1 1/4	2 1/2	14	3/4	1 1/8	3 7/8	.8750 / .8735	.4525 / .4475	.8770 / .8755	9/32
4	4.002 / 3.998	3.995 / 3.992	5 3/8	5 1/2	1 1/4	2 1/2	14	3/4	1 1/8	3 7/8	1.0000 / .9985	.5150 / .5100	1.0020 / 1.0005	9/32

RECOMMENDED STANDARD DIMENSIONS OF KEYS AND KEYSEATS

By Baker Brothers, Toledo, Ohio

The subject of adopting dimensions of keys and keyseats is one that is now attracting considerable attention among progressive manufacturers. The annoyance of fitting keys to work of various widths, depths and tapers, can hardly be estimated, and unless some standard uniformity of sizes is adopted, duplicate work cannot be produced. We have standard sizes for taps, drills, wire and gear teeth, and standard tapers for twist-drill shanks. Why not for keys and keyseats? The subject is one to which our attention has frequently been called, and realizing the need for something of the kind we have, after careful study and experience, prepared the following rules, together with Fig. 188 and Table XXXVII.

General Rule

The width of the key should equal one-fourth diameter of shaft.

The thickness of the key should equal one-sixth diameter of shaft.

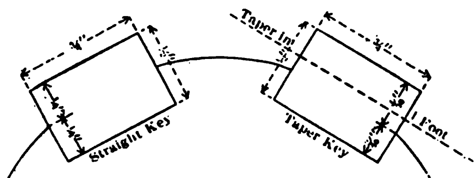


FIG. 188.—Recommended proportions of keys and keyways.

The depth in hub for a straight keyseat should be one-half thickness of key.

The depth in hub at large end, for a taper keyseat, should be three-fifths thickness of key.

Standard taper for all keyseats should be 3/16-in. in 1 ft. of length.

The depth to be cut in hub for taper keyseats, at large end, is greater than those cut straight, for the reason that unless this was done the depth in hub at small end would not be sufficient, especially in long keyseats.

The depths of keyseats in table are given in thousandths of an inch, corresponding to the graduations on the index of our micrometer depth gage, and is measured from the edge of keyseat, and not from the center. In this manner the exact depth of keyseat can be measured at any time after it is cut.

For extra long keyseats the depth cut in hub might be slightly increased, but for the average run of work the table will be found correct.

Manufacturers who adopt this rule will always find their keyseats of correct proportion, and will have no difficulty in duplicating their work, thus saving themselves much care and annoyance.

TABLE XXXVII.—RECOMMENDED DIMENSIONS OF KEYS AND KEYSEATS

Size of hole, inches	Decimal equivalent	Preferred width of keyseat	Nearest size of cutter	Preferred thickness of key	Nearest fractional thickness	Depth to be cut in hub for straight key	Depth at large end for taper key
1	1.	0.25	1/4	0.166	3/16	0.093	0.112
1 1/16	1.062	0.265	1/4	0.177	3/16	0.093	0.112
1 1/8	1.125	0.281	1/4	0.187	3/16	0.093	0.112
1 3/16	1.187	0.296	5/16	0.198	7/32	0.109	0.131
1 1/4	1.25	0.312	5/16	0.208	7/32	0.109	0.131
1 5/16	1.312	0.328	5/16	0.219	7/32	0.109	0.131
1 3/8	1.375	0.343	3/8	0.229	1/4	0.125	0.15
1 7/16	1.437	0.359	3/8	0.239	1/4	0.125	0.15
1 1/2	1.5	0.375	3/8	0.25	1/4	0.125	0.15
1 9/16	1.562	0.39	3/8	0.26	1/4	0.125	0.15
1 5/8	1.625	0.406	7/16	0.271	9/32	0.141	0.168
1 11/16	1.687	0.421	7/16	0.281	9/32	0.141	0.168
1 3/4	1.75	0.437	7/16	0.292	9/32	0.141	0.168
1 13/16	1.812	0.453	7/16	0.302	9/32	0.141	0.168
1 7/8	1.875	0.468	1/2	0.312	11/32	0.171	0.206
1 15/16	1.937	0.484	1/2	0.323	11/32	0.171	0.206
2	2.	0.5	1/2	0.333	11/32	0.171	0.206
2 1/16	2.062	0.515	1/2	0.344	11/32	0.171	0.206
2 1/8	2.125	0.531	1/2	0.354	11/32	0.171	0.206
2 3/16	2.187	0.547	1/2	0.364	11/32	0.171	0.206
2 1/4	2.25	0.563	1/2	0.375	11/32	0.171	0.206
2 5/16	2.312	0.578	1/2	0.385	11/32	0.171	0.206
2 3/8	2.375	0.593	5/8	0.396	7/16	0.218	0.262
2 7/16	2.437	0.609	5/8	0.406	7/16	0.218	0.262
2 1/2	2.5	0.625	5/8	0.416	7/16	0.218	0.262
2 9/16	2.562	0.641	5/8	0.427	7/16	0.218	0.292
2 5/8	2.625	0.656	5/8	0.437	7/16	0.218	0.262
2 11/16	2.687	0.672	5/8	0.448	7/16	0.218	0.262
2 3/4	2.75	0.687	5/8	0.458	7/16	0.218	0.262
2 13/16	2.812	0.703	5/8	0.469	7/16	0.218	0.262
2 7/8	2.875	0.719	3/4	0.479	1/2	0.25	0.3
2 15/16	2.937	0.734	3/4	0.49	1/2	0.25	0.3
3	3.	0.75	3/4	0.5	1/2	0.25	0.3
3 1/8	3.125	0.781	3/4	0.521	1/2	0.25	0.3
3 3/16	3.187	0.797	3/4	0.531	1/2	0.25	0.3
3 1/4	3.25	0.812	3/4	0.542	1/2	0.25	0.3
3 3/8	3.375	0.844	7/8	0.562	5/8	0.312	0.375
3 7/16	3.437	0.859	7/8	0.573	5/8	0.312	0.375
3 1/2	3.5	0.875	7/8	0.583	5/8	0.312	0.375
3 5/8	3.625	0.906	7/8	0.604	5/8	0.312	0.375
3 11/16	3.687	0.923	7/8	0.614	5/8	0.312	0.375
3 3/4	3.75	0.937	7/8	0.525	5/8	0.312	0.375
3 7/8	3.875	0.969	1	0.646	11/16	0.343	0.412
3 15/16	3.937	0.984	1	0.656	11/16	0.343	0.412
4	4.4	1.	1	0.666	11/16	0.343	0.412

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